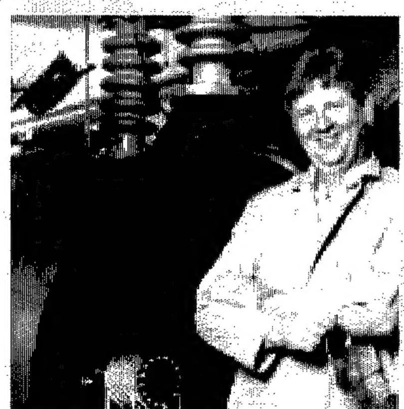
Annual Review



Army Research Laboratory

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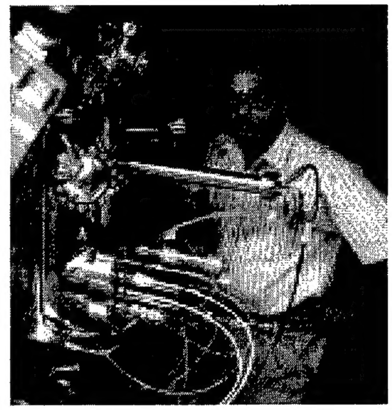
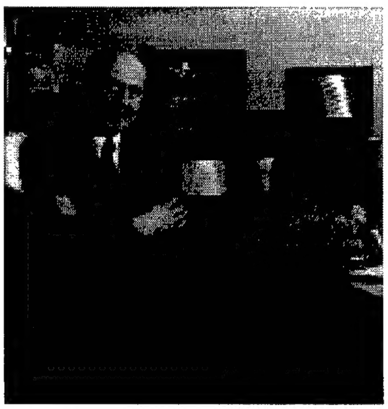
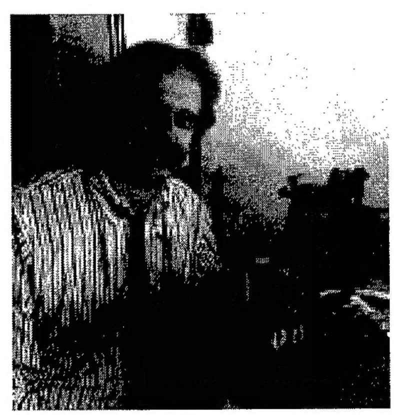


The U.S. Army Research Laboratory (ARL) is the Army's primary source of fundamental and applied research. Its mission is to provide the Army with the key technologies and analytical support necessary to ensure supremacy in future land warfare. ARL—with its state-of-the-art facilities and workforce, which includes about 1,250 scientists and engineers—constitutes the largest source of integrated science and technology services in the Army. The lab occupies two major sites, both in Maryland: the Adelphi Laboratory Center (ALC) and the Aberdeen Proving Ground (APG). It operates unique outdoor facilities at the White Sands Missile Range (WSMR) in New Mexico. The lab also has two research elements that are collocated with National Aeronautics and Space Administration (NASA) activities in Cleveland, OH, and Hampton, VA. ARL also receives considerable benefit from the Army Research Office (ARO) in Research Triangle Park, NC, which was recently realigned with the lab.



This review provides a look ahead. It focuses on ARL's initiatives to meet its *grand challenges* and support the Army After Next (AAN) process. It also presents highlights of the Federated Laboratory (FedLab) program and other recent ARL accomplishments, both technical and managerial. This review, primarily covers activities and accomplishments by ARL before the realignment of ARO, which officially occurred at the beginning of fiscal year 1999.



Message From Dr. Lyons

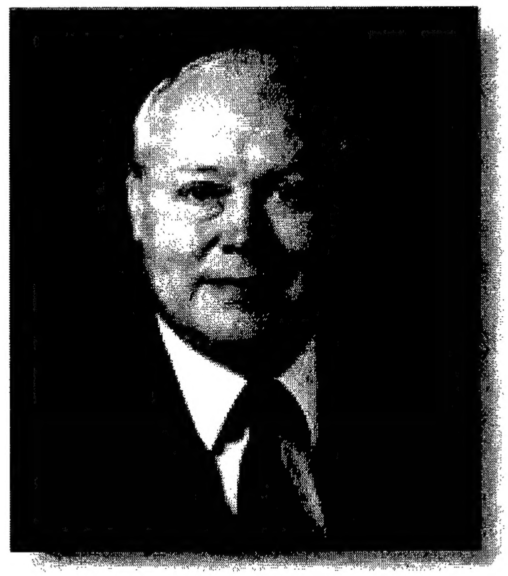
Fiscal year 1998 was another exciting year at ARL. Highlights include the receipt of four Hammer Awards from Vice President Gore and the announcement that ARO would be joining us. The Hammer Awards were presented by the Vice President through the National Partnership for Reinventing Government. The awards were given in recognition of ARL's development of the Personnel Demonstration project (shared), its implementation of the FedLab initiative, its development of the Turbine Engine Diagnostic System, and the Lab's Department of Defense (DoD) Small Business Innovation Research (SBIR) process reform. On 1 October 1998, following several months of planning, ARO was transferred to ARL. This move is intended to strengthen coordination of the Army Materiel Command's (AMC's) basic research program and facilitate synergism.

In the AAN process, ARL supports the Training and Doctrine Command (TRADOC) in its effort to look ahead 25 years or more and envision the battlefield of the future. ARL continues to focus on its *grand challenges* to provide enabling technologies in areas identified in the Army Plan and the AAN process. ARL is placing increasing emphasis on the information assurance thrust. Indeed, ARL has been recognized by the defense community as one of the Army's centers of expertise in the computer security area.

This marks the completion of my five-year tenure as Director of ARL. During this time, we have accomplished much. We have built two superb new laboratories at APG and ALC for the staff and functions that have been consolidated under the 1991 Base Realignment and Closure Commission process (BRAC 91). In 1994, we were designated a Major Shared Resource Center (MSRC) of the DoD High-Performance Computing Modernization Program, and we continue to acquire new supercomputing capabilities under that program. In December 1994, we conducted a successful proof-of-principle demonstration of the global positioning system (GPS) registration fuze for artillery rounds. Over the years, we can count achievements in such diverse areas as robotics, battlefield visualization, wideband radar, ferroelectrics, composite materials, wave-rotor technology, and live-fire prediction and assessment. Meanwhile, ARL provided support to U.S. soldiers deployed in Somalia, Haiti, Bosnia, and elsewhere around the world.

These have been productive years, made possible by the hard work of the outstanding professional and support employees at ARL. I know the staff will work just as hard with the new director, Dr. Robert W. Whalin, who comes to AMC and ARL from the U.S. Army Corps of Engineers Waterways Experiment Station (WES). Dr. Whalin had a distinguished record at WES, where he more than tripled the size of its research and development (R&D) program. He has great people and exceptional facilities here at ARL, and I wish him well as he takes the reins.

Message From Dr. Whalin



The Army of the future must be a versatile, mobile, deployable, power-projection fighting force. We at ARL are preparing now to meet the challenges of 2010 and beyond.

We seek out the best ideas and research from all sources to put them to work for the soldier. We manage the Army's basic science research grants with academia. We are leveraging the technology investment of the commercial sector and tapping the leading-edge expertise and facilities of universities and private industry. We are working closely with TRADOC and the R&D assets throughout AMC to develop the enabling technologies for the future Army.

As the Army's corporate research laboratory, ARL addresses the Army's needs across the total spectrum: today's Army of Excellence, Force XXI, Army/Joint Vision 2010, and the AAN. We must balance our investment strategy to meet the Army's requirements today and into the future. However, we focus on the *front-end* work, the basic science, to deliver science and technology products for the far term.

The AAN process has generated numerous recommendations for investment in basic research, including terrain- and environment-independent communications and data management, lightweight protective materials, and unmanned vehicles and robotics concepts. Some of the technology areas in which ARL works and which have been identified as potentially enabling for the AAN force are

- hybrid power systems,
- fuel efficiency,
- human and cognitive engineering,
- signature control,
- protection schemes for land systems,
- advanced materials,
- alternative propellants,
- chemical and biological protection, and
- logistics efficiencies.

We are pursuing exciting research at ARL that will greatly enhance the capabilities of the American soldier of the twenty-first century. I am proud to be part of ARL's long and productive tradition, and I invite you to review some of our recent accomplishments.

Partnering at the Crossroads

One of ARL's main thrusts is to put *the best and brightest* to work solving Army problems. Within the Army's basic research program, ARL employs a variety of funding mechanisms to support and exploit programs at colleges and universities and in private industry. By leveraging the facilities and resources of academia and industry, ARL complements its internal research efforts and focuses more world-class talent on Army challenges.

ARO

The realignment of ARO with ARL will strengthen the coordination of AMC's basic research program, and position AMC more effectively for making strategic investment decisions. On 28 September 1998, General Johnnie E. Wilson, Commander, AMC, installed Dr. Jim C. I. Chang as the new Director of ARO and as ARL's Deputy Director for Basic Science.

ARO leverages an annual Army investment of about $51M into a total annual program of more than $260M. In fiscal year 1998 (FY98), the total of active grants and contracts managed by ARO came to about $650M. ARO's current work focuses on leap-ahead capabilities for the AAN. This includes work on microturbines for lightweight energy sources and functionally tailored textiles for protection.

Historically, ARO primarily funded single-investigator research projects, but since the 1980s, it has established a number of Centers of Excellence (COEs) that join together a number of scientists and engineers with often expensive research instrumentation. ARO also manages the Army part of the DoD University Research Initiative (URI) Program. Under this umbrella, ARO establishes several new Multidisciplinary University Research Initiatives (MURI) each year. An MURI typically engages two or more scientific/engineering departments within a university on a project that requires more than one specialty and is usually funded at $1M a year for five years.

FedLab

ARL's Federated Laboratory construct—FedLab—is an innovative approach to integrating external research that is relevant to battlefield information systems—where the private sector has a substantial technology capability—with internal resources through the establishment of consortia in critical technological areas. This approach leverages external expertise, facilities, and technologies in areas where the private sector has both the lead and the incentive to invest.

In January 1996, ARL launched the FedLab initiative, entering into cooperative agreements with industry and university partners to form three consortia: Advanced Telecommunications and Information Distribution, Advanced Displays and Interactive Displays, and Advanced Sensors.

The dynamic feature of the FedLab concept is the cumulative effect of the shared resources, both people and facilities. FedLab members are applying more of their facilities and research talent than is funded by the program. In February 1998, ARL held its second annual Federated Laboratory Technology Symposium.

Outreach

Between them, ARL and ARO manage 20 COEs. Notable external partners include the Army High-Performance Computing Research Center (AHPCRC) at the University of

Minnesota; the Institute for Advanced Technology at the University of Texas (Austin), which is doing hypervelocity phenomena work; and the Information Sciences Center at Clark Atlanta University, with its software engineering efforts. ARL also has cooperative agreements that support microelectronics, including one with the Johns Hopkins University and one with a consortium headed by the University of Maryland. Collaborative programs in materials research are conducted with Johns Hopkins, the University of Delaware, and the Michigan Molecular Institute.

ARO has pursued an active Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) program since the early 1980s. It has been designated by the Department of the Army as the AMC and Army lead for HBCU/MI oversight and proponency.

ARL has six HBCU/MI partners in its FedLab program: the City University of New York, the University of New Mexico Center for High Technology Materials, Howard University, Clark Atlanta University, North Carolina Agricultural and Technical State University, and Morgan State University. In addition, there are four HBCU/MI partners in the AHPCRC: Florida A&M University, Clark Atlanta University, Howard University, and Jackson State University. ARL also has a microelectronics partnership with Howard.

Army After Next

The Army's Chief of Staff asked TRADOC to study issues vital to the development of the Army to about the year 2025. TRADOC created a process of inquiry and critical evaluation that links the development of doctrine, tactics, leadership, and materiel through an annual cycle of workshops and conferences followed by tactical and strategic war games. This cycle culminates in an annual report to the Chief of Staff.

AMC plays an important role in addressing technology and materiel solutions to the operational requirements identified in the process. The AMC Commander selected ARL to lead AMC's support of AAN. ARL has supported the technology team at the 1997 and 1998 winter war games and has organized integrated idea teams to translate operational capabilities conceived by doctrine designers into viable notional systems to be fed back into the cycle for further evaluation.

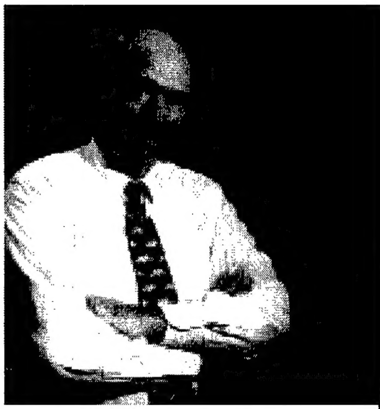
The Army Plan of March 1998 says, in part:

> *We will defer the acquisition of most next-generation systems to focus [science and technology], research and development, and the industrial base on the identification and development of leap-ahead systems to support the AAN.*

With this in mind, the Army set three priorities for equipment modernization: information dominance, physical agility, and lethality and survivability overmatch. ARL is focusing on technologies that provide warfighters with significantly improved capabilities in all three areas. These are ARL's grand challenges; they include

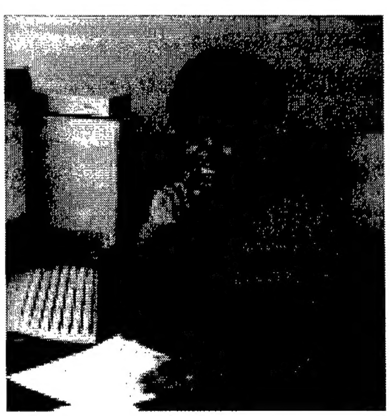
- innovative weapons systems technologies for future combat systems;
- lighter, faster, more fuel-efficient mobile platforms to enhance deployability and reduce the logistics tail;
- unprecedented real-time situational awareness for commanders on the battlefield;
- significant improvements to the battlefield soldier's ability to absorb information and make decisions; and
- solutions to the defensive information warfare problem.

More details of ARL's contributions to these technology areas are given throughout this review.



Future Combat Systems

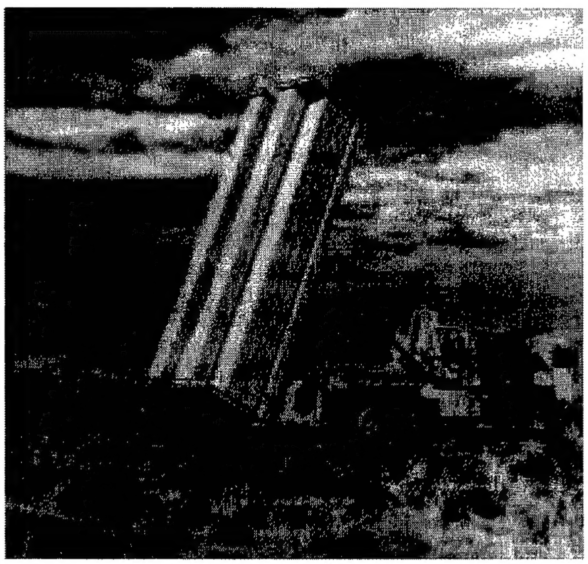
Our fast-paced, flexible forces of the future must be more lethal and more capable of surviving. ARL conducts research for the development of future combat systems that focuses on the Army's unique and emerging needs for advanced armor, armaments, and survivability. By developing leap-ahead technologies, ARL will provide innovative weapons systems technologies for future combat systems (FCSs).



Air Defense Systems

During FY98, ARL performed a comprehensive vulnerability risk assessment of the Theater High Altitude Area Defense (THAAD) system versus electromagnetic environmental effects (E^3) in support of the Milestone II decision review. This comprehensive analysis involved an evaluation of the effects of all major E^3 elements: electromagnetic interference (EMI), EM radiation operations (EMRO), EM radiation hazards (EMRH), EM pulse (EMP), electrostatic discharge (ESD), and lightning effects (LE) on the critical functions and critical subsystems/components of the THAAD system in accordance with a detailed analysis matrix.

The approach included a hierarchical analysis from the system level down to the critical component level. After a study of the adequacy of the E^3 criteria and the recommendation of modifications to the E^3 requirements by the E^3 Requirements Board (E^3RB) as requested by the Secretary of the Army for Research, Development, and Acquisition (SARDA), ARL assessed individual subsystem impact by all major E^3 elements. This evaluation culminated in an E^3 vulnerability risk assessment of system performance/ effectiveness. This analysis addressed the severity of system performance impact/degradation and the likelihood of encountering the various EM operational environments. Available data, measured and/or validated as a result of tests and/or simulation exercises, were used to provide associated E^3 assessment confidence ratings. Additionally, a detailed Soldier Survivability (SSv) assessment for the THAAD system was conducted to substantiate previous assessment conclusions. In the area of conventional weapons (in particular, long-range guided munitions), the analysis focused on the THAAD User Operational Evaluation System (UOES) prototype configuration and specific long-range lethal weapon threats to the soldier. A Stochastic Analysis of Fragment Effects (SAFE) simulation analysis approach was employed to quantify SSv issues. In the area of chemical/biological weapons, further analysis was done on the nuclear, biological, and chemical (NBC) capabilities of the radar Operator Console Unit shelter, based on the UOES configuration. The analysis focused on the nuclear biological chemical contamination survivability (NBCCS) decontamination aspects. This analysis has also sustained the overall evaluation conclusions in the previous assessment. Further analyses in other areas of lethal weapon vulnerability risk assessment are essentially complete and will provide the technical detail required for the Theater High Altitude Area Defense (THAAD) milestones (MS) II evaluation.



THAAD System

Impact: These specialty engineering analyses directly address the Operational Test and Evaluation Command (OPTEC) System Evaluation Report survivability issues in support of the THAAD MS II decision.

Aviation Systems

In FY98, ARL received a commitment from the Comanche helicopter Project Manager's Office (PMO) to support continuation of the analysis of the potential airborne chemical agent threat that the RAH-66 Comanche helicopter could experience on the modern

battlefield. Work in this area in FY97 that had examined the effects of two specific blood agents was documented in a technical report that was distributed to the Comanche PMO and other Comanche acquisition-related offices. A follow-on study was conducted to identify potential modeling scenarios with two nerve agents, GD and HX, and the blister agent, HD. The chemical/biological agent dispersion computer model—Vapor, Liquid, Solid Tracking (VLSTRACK)—was used to model various operating scenarios and predict the potential exposure levels and duration for a variety of conditions. The baseline modeling scenario development was completed in FY98 in coordination with the RAH-66 Comanche helicopter developer, Boeing/Sikorsky. Coordination continued with the Comanche PMO, and scenarios were detailed and continued sponsorship and funding support for the effort were confirmed. Data runs for the GD nerve agent and the HD blister agent were completed using an updated version of the VLSTRACK model. The VX nerve agent data runs and analysis were anticipated by early November 1998. A draft report on the entire task was planned to be available by 31 December 98.

Comanche helicopter

Impact: ARL's analysis has provided the RAH-66 Comanche developers and users with the potential airborne chemical agent challenge levels based on realistic battlefield exposure scenarios. The results of this analysis will be used as a baseline exposure level for further system and subsystem level assessments.

Ground Systems

Since the In Process Review (IPR) by the Program Executive Officer, Ground Combat and Support Systems (PEO GCSS), and Commandant, U.S. Army Field Artillery School, on 12 March 1998, the ARL Crusader team has continued its support to the contractor's detailed design process for the Crusader advanced field artillery system and to the continuous test and evaluation activities by the Army's Independent Evaluator—OPTEC Evaluation Analysis Center (EAC). These efforts led to the System Level Design Review No. 2, scheduled for November 1998. Extensive technical support has also been provided to the United Defense Limited Partnership (UDLP—the Crusader contractor) Survivability, Armament, Mobility Integrated Process Teams (IPTs). Component level target descriptions of the self-propelled howitzer and the re-supply vehicle were to be completed by mid-December 1998. The next set of experiments and analysis on propellant compartmentalization and fire suppression was planned to be completed by the end of the first quarter FY99. A team was established to review/monitor the contractor's work on susceptibility reduction and support to force-on-force simulation work. The review was completed, and a follow-on briefing was given to the Crusader PM. A final report on the review is also being prepared.

Impact: These efforts have influenced the Team Crusader (PM and contractor) design and development process, which will result in enhanced vehicle and crew survivability.

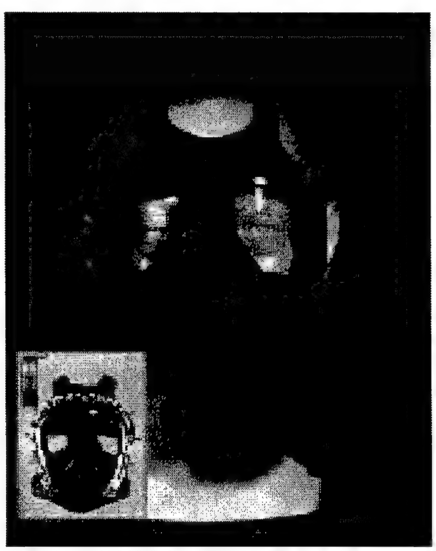
Munitions Systems

In support of the Army Tactical Missile System (ATACMS) Block IA Follow-on Test, ARL developed a fuel fire model based on fuel fire experiments, a fragment sensitivity analysis, and pyrophoric characterizations. Additionally, vulnerability data analysis was completed to support the ATACMS system effectiveness analysis and evaluation for attack/utility helicopters, surface-to-air missile (SAM) site elements, ammunition stacks, and fuel tanks (one-half full and completely full). ARL used the results from the follow-on test to recommend changes to the criticality analysis supporting the vulnerability inputs to the system effectiveness study. Additionally, in support of the 1 May 1998 MS III decision on ATACMS Block IA and to help develop credible model predictions for a foreign helicopter, ARL conducted selected M74 bomblet shots against a helicopter fuselage and surrogate sponson fuel tank. The results of these shots and comparisons with model predictions have been documented. Formal survivability reports on an ammunition vulnerability analysis, a helicopter vulnerability analysis, a fuel fire model, and preshot predictions have also been written in support of the ATACMS Block IA program. Formal survivability reports on a SAM site vulnerability analysis, a fragment sensitivity analysis, a damage assessment and model comparison for helicopter shots, and an improved model predictions analysis were also being written during FY98.

Impact: This effort provided data required by the ATACMS Block IA FY97 Low Rate Initial Production Decision Memorandum. It also supported the development of the FY99 Target Interactive Lethality Vulnerability Plans to include ammunition vulnerability and fuel fire tasks, thus allowing improved modeling and more accurate interactive predictions. Additionally, ARL provided quantified lethality estimates that were essential to the evaluation conducted in support of the third-quarter FY98 MS III decision.

Protective Mask Research

In coordination with the Edgewood Chemical Biological Center's (ECBC's) Respiratory Protection Group, ARL is seeking to develop computer design analysis tools that will form part of an expert design system for assessing and optimizing mask designs before the creation of prototypes. Presently, mask development follows an extensive iterative design, prototype, and test process that can be slow, costly, and unresponsive to changing user needs. An expert design tool would enable mask developers to efficiently design and analyze concepts, respond rapidly to requirement changes, and provide users with masks with enhanced performance, compatibility, and reduced physiological burden.



Headform with mask and inset showing pressure profile

In FY98, ARL awarded a Phase II Small Business Innovation Research (SBIR) contract to model the interface of a protective mask with the human face to determine contact pressures in order to assess mask fit and comfort. This model will use computer-aided design (CAD) models of the mask, laser scans of head geometry, material properties of the mask and human facial tissue, and definition of the boundary conditions and constraints in a finite element analysis to determine the pressures required to achieve a comfortable, yet protective fit of the mask. In support of this effort, ARL completed an evaluation to develop a relationship between mask seal pressure and fit and

will support development of a pressure and comfort relationship in the future. There is external interest in this research effort; consequently, ARL is initiating cooperative relationships with the Air Force Research Laboratory and private industry.

ARL will digitize common equipment interfaces to assess the compatibility of proposed mask designs with existing equipment using CAD. In addition, design envelopes for future masks can be created based on the examination of the interfaces of a wide array of equipment.

Impact: The work under this project will dramatically change the mask design process as well as define the continued innovations needed and the additional research required to respond to the future challenges in respiratory protection.

Maintenance on the Future Battlefield—Diagnostic Processes

ARL is working to improve Army maintenance diagnostics by developing soldier performance models of manual and computer-aided diagnostics processes. These models will allow developers to assess new technologies, procedures, and equipment against a performance baseline. Started in FY98, this project is a joint effort with the Army Materiel Systems Analysis Agency (AMSAA).

Soldiers using diagnostic test system on a truck

ARL and AMSAA collected soldier demographics, environmental conditions, and maintenance diagnostic times and error-rate data from active and reserve units that were performing daily maintenance operations. The initial study focused on manual and computer-aided diagnostics of tactical wheeled vehicles. Additional data were collected on the soldiers' acceptance of maintenance diagnostic tools. An analysis of these data demonstrated the direct importance of a soldier's grade (and, therefore, indirectly his or her experience and training on Army equipment) in determining actual diagnostics times. The study is using the data to construct baseline soldier performance models of vehicle electrical and mechanical diagnostic tasks to evaluate the cognitive, visual, auditory, and psychometric workloads during the manual and computer-aided diagnostics.

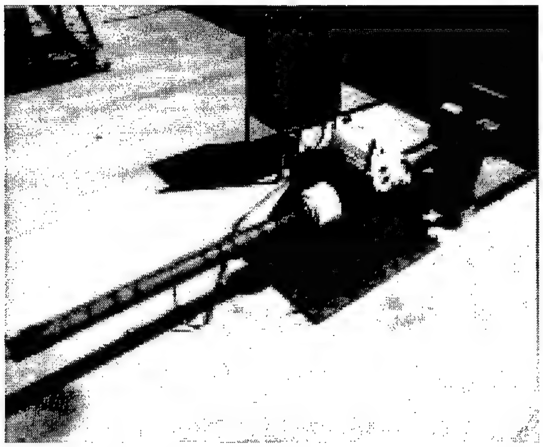
Future efforts will center on ways to reduce the high no-evidence-of-failure (NEOF) rates found in both Army and commercial systems. These diagnostics errors drive up operating costs of critical Army systems and reduce readiness.

Impact: This effort will provide the technology developer the critical information and tools needed to evaluate new maintenance technologies from a human factors perspective and reduce warfighter and maintenance workloads.

Electric Armaments

ARL is investigating electric armaments technologies because of their potential leap-ahead capabilities to defeat future threats, including those equipped with reactive armor and active protection systems. Electric armaments technologies relate to the concept of launching projectiles using electrical energy, either exclusively (EM propulsion) or with chemical energy from propellants (electrothermal-chemical (ETC) propulsion).

Feasibility tests of ETC ignition concepts were conducted with the M256 120-mm tank cannon. The ignition designs tested included the flashboard large-area radiation emitter (FLARE), triple coaxial plasma ignition, and compact ignition. The FLARE design was further tested with a Fastcore propellant configuration, with good progress demonstrated toward the 14-MJ muzzle energy goal.



Experimental 120-mm ETC gun

Continued progress was made on pulsed-power technology for EM launchers. Dynamic load testing of the subscale compulsator, a rotating-machine pulsed-power concept selected for EM launch research, was conducted at close to exit-criteria design specifications. The compulsator was tested to 11,500 rpm and is being prepared for a final test at 12,000 rpm—the full-performance design point.

Another element of the Electric Armaments Program is the investigation of the relationship between hypervelocity and projectile lethality. Impact physics experiments were conducted and show that novel kinetic-energy penetrators are capable of defeating advanced targets when launched at hypervelocity.

Impact: Successful development of electric armaments and associated subsystem technologies will provide lethality overmatch and simplified logistics for future combat vehicles.

Advanced Kinetic-Energy Cartridge

The Advanced Kinetic-Energy Cartridge Program is part of the Direct Fire Lethality Advanced Technology Demonstration (ATD), aimed at developing projectile lethality technology that can defeat armored vehicle threats that are equipped with explosive reactive armor at extended ranges and improved system accuracy. ARL is supporting the Armament Research, Development and Engineering Center (ARDEC) under this program by conducting in-depth investigations of the interaction of kinetic-energy penetrators and explosive reactive armors.

A physics-based model was developed that predicts explosive initiation under a variety of conditions, including penetrator shape, diameter, obliquity, and material; armor plate and air-gap thicknesses; and explosive formulation and configuration. Predictions of the model are being validated by experiments, and the model is being optimized based on the experimental results.

Impact: Advanced designs in kinetic-energy projectiles will provide improved lethal mechanisms for antiarmor lethality that can overmatch emerging armors.

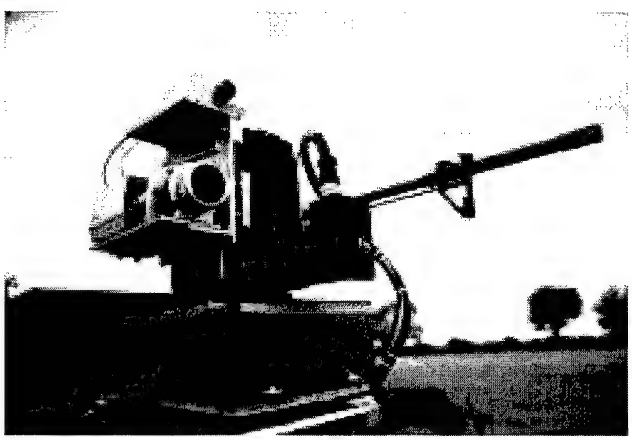
Rocket Accuracy Technology

To improve the accuracy of helicopter-fired rocket systems, ARL is investigating launch disturbances and other dominant error sources of these systems. A finite-element model was developed for the Hydra-70 rocket launcher pod, and pod-motion measurements were made during hardstand ground test firings at the Aberdeen, MD, and Yuma, AZ, proving grounds. The experimentally determined angular pod displacements are being put into a six-degree-of-freedom computational code to assess the effect of launcher motion on rocket accuracy. Further experimentation using air-launch tests will be conducted in FY99.

Impact: Integration of low-cost guidance, navigation, and sensing components into the 2.75-in. rocket system will significantly improve its accuracy.

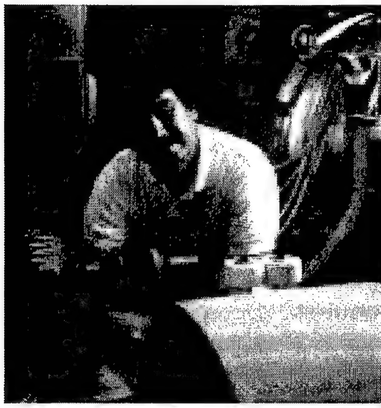
Inertial Reticle Fire Control

The Inertial Reticle System is a novel fire-control system that uses state-of-the-art video, computational, and inertial sensing technology to improve the accuracy of direct-fire weapons. It is designed for use in both individual and crew-served small-caliber weapons as a low-cost alternative to mechanical stabilization.



Inertial Reticle System mounted on a vehicle

Following earlier testing of the Inertial Reticle System with an M16 rifle mounted on a fast attack vehicle, further extensive field testing was conducted using a 0.50 caliber machine gun mounted on a high-mobility multipurpose wheeled vehicle (HMMWV). The testing indicated significant improvement in the performance of an operator firing the weapon in semiautomatic mode at a static target using the Inertial Reticle System.



Enhanced Platform Deployability

As we move to a U.S.-based Army in which force must be projected around the world, our systems must be strategically deployable. Research advances in vehicle propulsion, structural mechanics and dynamics, material science, manufacturing technology, and other related fields must be achieved to give the future Army effective, survivable, and affordable air and ground vehicle systems with the performance edge to win on the battlefield with lower operating and support costs.

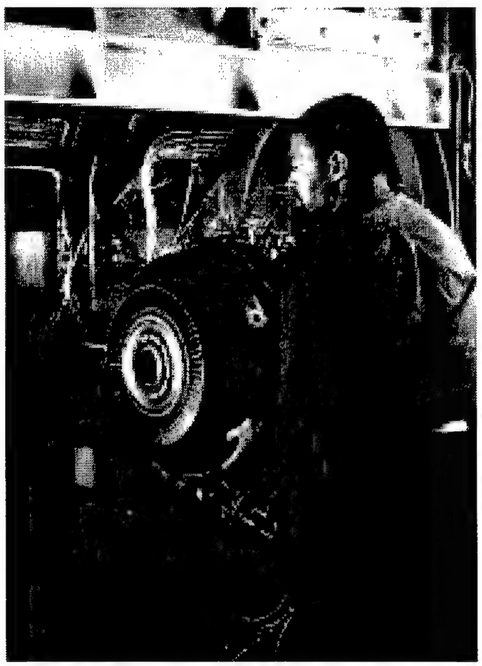
ARL's research and development efforts will provide lighter, faster, and more fuel-efficient mobile platforms to enhance deployability and reduce the logistics tail.

Army After Next Fuel-Efficiency Thrust

An AMC white paper entitled *Fuel-Efficient Army After Next* (March 1997) concluded that a 75 percent reduction in the battlefield fuel requirement, based on the needs of today's Army of Excellence (AOE), is technically achievable by 2020. This level of fuel reduction will be necessary if the Army After Next (AAN) vision for deep penetration is to be realized. However, the current and foreseeable inventory of vehicles cannot satisfy AAN mission goals, so an enhanced S&T program, one specifically focused on fuel-efficient technologies, must be undertaken.

In June 1998, ARL convened a national study group to examine the issues in greater detail. Over 60 experts attended, representing industry, the RDECs, the Training and Doctrine Command (TRADOC), ARL/ARO, DARPA, NASA, the Secretary of the Army for Research, Development, and Acquisition (SARDA), and academia. They were tasked to

1. validate the overall goal of 75 percent fuel reduction,
2. develop a detailed enabling technology plan, and
3. conduct an in-depth analysis of the potential cost savings and/or other benefits to the Army.



Engine test stand at NASA's Glenn Research Center

Working assumptions included a long-term global energy source outlook, applicable commercial programs and technologies, and the role of legacy and upgraded legacy systems in the AAN timeframe. The group analyzed investment strategies for five key thrust areas:

- propulsion;
- materials and structures;
- armor, including active protection systems;
- mobility and platform concepts; and
- usage and tactics.

In October 1998, the group findings were integrated into an AAN Technology Program Plan that included roadmaps and programmatic recommendations.

Impact: This initiative will enable advanced fuel-efficient technologies to be developed and available in time for AAN operations.

Innovative Composite Fuselage Design for Improved Crashworthiness

ARL and NASA are engaged in a multiyear cooperative research program to develop and evaluate an innovative and cost-effective composite fuselage concept for improved crashworthiness. The fuselage concept will be demonstrated through fabrication and testing of a one-fifth scale model, which will lead to the final evaluation of a full-scale prototype. The fuselage concept consists of a relatively rigid upper section, or passenger cabin; a stiff structural floor; and a frangible lower section that encloses the crash energy management structure. In FY98, five different subfloor configurations were developed, analyzed, and tested to ensure that the fuselage section of the model would achieve and maintain survivable floor-level acceleration requirements. These subfloor configurations include a composite sandwich shell for the lower subfloor surface, a crushable foam insert, discrete energy-absorbing subfloor beams, crushable tubular inserts, and an isogrid-type concept with interconnecting beam segments.

In addition to the impact conditions, these configurations were designed to be easily manufactured using low-cost materials and fabrication techniques, and are expected to exhibit good energy-absorption behavior under off-axis and purely vertical impact conditions. Quasi-static and impact tests were performed to evaluate the energy-absorption potential of each subfloor configuration. In addition, design modifications to the most promising subfloor configurations have been made using MSC-DYTRAN finite element simulations. The choice of subfloor configuration has been narrowed to either the transverse tube or foam-filled configurations.

Impact: This research paves the way for an innovative concept of aircraft fuselage structural design that can realize crashworthiness goals and objectives while avoiding the reliance on *after-design* modifications.

Rotorcraft Structures Damage Tolerance and Durability

The technical challenges for composite structures in rotorcraft are (1) to ensure structural integrity while making extensive use of composite materials, (2) to provide cost competitiveness with aluminum, and (3) to provide low-initial design and manufacturing costs as well as substantially reduced life-cycle costs. To achieve efficiency and affordability one needs to consider both the airframe and dynamic components of rotorcraft structures. Low-cost structural design concepts along with reliable analysis and design methods that are based on durability and damage tolerance and residual strength will lead to efficient and affordable airframe structural concepts.

In FY98, ARL investigated various methodologies to address vital composite design issues, including (1) delamination characterization, (2) fatigue durability of composite rotor hub flexbeam laminates, and (3) durability and damage tolerance design criteria for composite skin/stringer airframe components. In all cases, preliminary technical papers were generated to document the year's significant findings.

In the area of delamination characterization, interlaminar shear fracture toughness and standardized interlaminar fracture test methods were documented in two journal articles. A double cantilever beam test was accepted as a draft international standard and a mixed-mode bending test method passed an American Society of Testing and Materials (ASTM) subcommittee ballot.

The work on fatigue durability of composite rotor hub flexbeam laminates established the viability of an improved fatigue-life prediction methodology. This analysis incorporated a geometric nonlinear finite element model of a main rotor hub flexbeam and will be extended to a statistical framework. It will include a look at hybrid glass and graphite epoxy flexbeams and examine the influence of ply waviness on flexbeam fatigue life.

The investigation of durability and damage tolerance design criteria for composite skin/stringer airframe components characterized the fatigue debonding behavior in thin-skin stringer-reinforced composite fuselage panels. It also provided greater insight into stiffener flange-to-skin bondline failures and the influence of combined membrane and bending loads on skin/stringer pull-off.

Impact: This in-house research will provide validated design tools to support the Aviation and Missile Command (AMCOM) Rotary Wing Vehicle structures technical objectives and the DoD total defense authority goals and payoffs. It is also a critical part of a multiyear joint effort with the NASA Design for Efficient Affordable Rotorcraft (DEAR) program.

Compression System Stability Enhancements

In pursuit of the goals of both the phase III Integrated High-Performance Turbine Engine Technology (IHPTET) program and the fuel-efficiency thrust of AAN, the gas turbine engine compression system is being driven to very high levels of loading. As compressor loading increases, operability becomes a severe problem. To address this, ARL has been exploring techniques to enhance compression system stability. In FY98 a high-speed, axi-centrifugal compression system rig test was conducted at AlliedSignal Engine Company to investigate stability enhancements for small gas turbines. This program used an air injection system installed upstream of the compressor first-stage rotor. This system counteracted pressure instabilities and, thus, extended the compressor's stable operating range. This technique demonstrated excellent penetration into the later stages of the compressor. Significant operating range extension was demonstrated at low speeds with steady injection. At higher speeds, however, the steady injection had only a limited effect on the machine. An enhanced control and/or actuation design will apparently be necessary for active stability control. The rig test results and findings will be published in an FY99 technical report.

Impact: The test provided valuable insights into the surge/stall phenomena of the high-speed multistage compressor that will influence the direction of future compressor stability research.

Management of Compressor Tip Clearance and Casing Treatment Flows

A remaining high-leverage area for aeroengine compressor performance improvement is the control of the leakage flow through the clearance gap between the moving compressor rotor blades and the stationary compressor casing. This clearance flow not only has an adverse impact on the steady-state performance of the compressor through all phases of the flight envelope, but it also impacts the stable operating envelope and, therefore, the safety of the compressor system. The use of slots and grooves in the casing over the blade tips, known as casing treatment, has been shown to improve the safe operating range of compressors, but only with an attendant loss in efficiency. The fluid mechanics mechanisms at work within casing treatments are not well understood and, as a result, treatments are designed on an experience-related, empirical basis rather than on a sound, first-principle basis. A collaborative ARL/NASA research effort is underway to address this problem on two fronts: (1) by improving our understanding of the controlling fluid mechanics phenomena through a combination of computational fluid dynamics (CFD) simulations and physical experiments, and (2) by applying lessons learned to the design and test of advanced casing treatments that could improve the safe operating range with little or no loss in efficiency.

In FY98, parametric CFD investigations were completed and are being analyzed to identify those fluid mechanics mechanisms that are most critical to achieving a successful casing treatment. Based on this effort, improved casing treatments will be designed and proof-of-concept tested under the direction of the lead Army research engineer. The results of these findings will be shared with the technical community through an interim technical report.

Impact: This research will lead to improved steady-state performance of the engine compressor through all phases of the flight envelope, and increase the stable operating envelope and overall safety of the compressor system.

High-Temperature MEMS Actuator for Boundary Layer Control

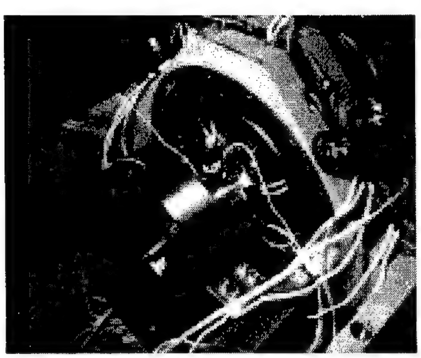
Microfabricated actuators for high-temperature applications represent a new area of the burgeoning field of microelectrical mechanical systems (MEMS). Silicon and silicon carbide are the most attractive materials for high-temperature MEMS applications because of their excellent mechanical properties and their compatibility with batch-fabrication techniques. Under certain off-design conditions, low-pressure turbines will lose efficiency due to the occurrence of laminar separation bubbles on the pressure surface. Vortices can be generated to prevent these separation bubbles from appearing by employing MEMS actuators upstream of the problem area. The actuators envisioned had a built-in heating resistor located between a bimetallic film of silicon carbide and nickel. Further investigation using finite-element modeling and experimental data with silicon actuators showed that this concept could not achieve the necessary normal displacement to generate the vortices. Furthermore, bimetallic actuators are inherently power hungry.

In FY98, a new actuator concept was invented that eliminates both of these problems. The new device uses electrostatic actuation and is capable of achieving normal displacements into the boundary layer of 100 to 200 μm. The actuators will be much more robust than the bimetallic types or the electromagnetic actuators now being tested by the University of California at Los Angeles (UCLA) and the California Institute of Technology (Caltech). The new actuator is equally suited for single-die or full-wafer applications. In FY99, this device will be fabricated in silicon in collaboration with NASA or with Case Western Reserve University, depending on the availability of the deep reactive ion-etching (DRIE) machine. The wafer-scale actuator will be tested in the laboratory and then in a low-temperature wind tunnel. Silicon carbide actuators are possible but deep reactive ion etching of silicon carbide is expensive and time consuming.

Impact: The new actuator concepts will enhance the efficiency and performance envelope of future turbine engines through the suppression of the laminar separation bubbles on the pressure surface.

High-Temperature Magnetic Bearings

Pursuit of the fuel-efficiency thrust for AAN and the IHPTET program Phase III system goals has created an aggressive future environment for turbine engine components. Aerodynamic and thermodynamic components must withstand greater loads, pressures, and temperatures at very high speeds. At these extremes, the supporting mechanical systems, such as bearings and seals, present possible obstacles. In response to this concern, research has been devoted to the investigation of high-temperature magnetic bearing technology. The potential benefits for gas turbine engines include (1) higher engine speeds; (2) oil-less and, therefore, lower part count/more reliable operation; (3) elimination of oil analysis and disposal; (4) stall and adaptive vibration control; (5) active blade vibration control; (6) active compressor tip clearance control; and (7) health monitoring. If successful, this technology will enable support for components that rotate at high speeds without having to solve the problem of high-temperature lubrication system/lubricants. At this time, the plans call for a demonstration of the magnetic bearing concept in the IHPTET program's XTC77/2 engine by the year 2002.



High-temperature magnetic bearings rig

In FY98, ARL collaborated with NASA's Glenn Research Center, Allison Advance Development Company, Texas A&M, and the University of Virginia to conduct initial testing to 6000 rpm and 800 °F. A limitation in the thermal expansion of the coil precluded more extensive investigations, but the potential for higher performance was clearly evident. The long-range goal of the program is to establish an experimental capability that will demonstrate magnetic bearing operation between 1000 to 1200 °F at 4 to 6 MdN. The main technological challenges are high-temperature wire and rotor lamination development.

Impact: This research will enable the design of lighter, more reliable, and more powerful turbine engines.

Oil Coking in Hot Section Bearings of the AGT-1500 Turbine Engine

Oil coking is one of the primary causes of engine failure for the AGT-1500 turbine engine (the M1 tank engine). It occurs when the engine has not been given sufficient time to cool down before the oil flow to the bearings is stopped. The residue of remaining oil is cooked by the high engine temperature and forms a layer of coke on the bearing surfaces. The major cause of heavy oil coking is improper engine shutdown. This problem is of major consequence logistically; if it is solved, it could significantly reduce engine overhaul costs, which now exceed $200K, and double the average life of an AGT-1500 engine.

In 1998, the primary effort addressing this problem was devoted to exploring the idea of integrating a minilubrication pump into the hot section bearing oil lines. This pump would sustain oil flows after turbine engine shutdown, until the heat in the bearings was safely below the oil coking temperature. Several off-the-shelf pump systems were bench tested and found to be capable of operating without failure. From these tests, a minilubrication fixture was designed that could be connected to a current AGT-1500 engine lubrication system without impacting its normal operation. The results from limited preliminary testing demonstrated an effective lowering of oil temperatures in the bearing compartment after engine shutdown. The next step will be to complete the minilube system design, which would involve fitting the system (lubrication and electronics) into the existing M1A1 tank environment and performing field tests for system robustness.

Impact: This investigation will provide a means to reduce or eliminate engine failure and overhaul that results from the build-up of excessive of oil coke due to improper engine shutdown.

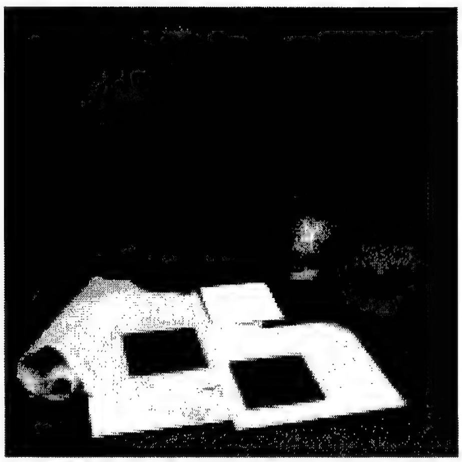
Micromechanics and Failure Modeling

ARL has been engaged in the development of such models for metals and for ceramics. For ductile metals, the Rajendran-Dietenberger-Grove (RDG) model represents the nucleation and growth of voids that lead to failure; material strength is degraded accordingly. A model for adiabatic shear banding, the other damage mechanism in ductile metals, has been developed. This model consists of a detection criterion and the subsequent degradation of both flow stress and spall stress. Crystal plasticity research is underway to explain textural anisotropies that develop in some metals (notably copper and titanium) during large deformation. In the area of ceramics, the Rajendran-Grove (RG) model the represents effects of brittle cracking on strength degradation: an initial crack distribution is prescribed, and cracks grow when the Griffith criterion is satisfied. All these models have been installed into the EPIC Lagrangian wavecode. In some cases, installation into the CTH Eulerian wavecode is a current activity.

Impact: Developing high-fidelity models that predict high-rate deformation and failure of materials under various loading conditions is the key to developing an in-depth understanding of complex armor/antiarmor mechanisms.

Ultralight Ballistically Resistant Materials

The U.S. armor community is engaged in an accelerated effort to develop armor designs that can defeat armor-piercing small-caliber threats at significantly reduced aerial weights. ARL is supporting a DARPA-sponsored program to develop a personnel armor system that can defeat a 7.62-mm armor-piercing M2 projectile at an aerial weight of 3.5 lb/ft^2 or less. The ARL effort features a material design effort integrated with experimentation and numerical simulation.



Ultralight ballistically resistant materials for individual soldier protection

The focus for the personnel armor system has been on a material system consisting of ceramic tile backed with a fiber-reinforced polymeric composite laminate. Candidate materials for the ceramic tile include aluminum nitrate (AlN), aluminum oxide (Al_2O_3), boron carbide (B_4C), and silicon carbide (SiC). Those for the composite laminates include glass/polyester, aramid/phenolic, and spectra/polyurethane.

Numerical simulation is being conducted to evaluate the effects of thickness, weight, and mechanical properties of the material components on the ballistic performance of the system. For fiber-reinforced composite laminates, a cohesive zone model is being developed that will significantly improve the predictive capability of personnel armor system modeling by treating delamination and fiber breakage. High-fidelity ballistic experimentation has allowed the elucidation of specific mechanical properties of the armor materials that are critical in defeating the 7.62-mm armor-piercing threat.

Impact: Successful application of ultralight ballistically resistant materials will enable the development of personnel and other light armor systems that can defeat small-caliber armor-piercing and fragmenting munition threats at significantly reduced weights.

Composite Armor Technology

ARL made several contributions to advance the state of the art of multifunctional armor technology based on the application of polymer-matrix composites, ceramics, elastomers, and other materials. Improvements were made in damage tolerance, ballistic testing, manufacturing, and repair.

High strain-rate characterization studies of integral armor and its individual components are supporting ongoing ballistic modeling efforts by providing insight into damage mechanisms. Further modeling and testing is allowing the improvement of damage-tolerance mechanisms, including ceramic tile confinement, composite backing stiffness, and elastomer layer thickness.

An innovative manufacturing method of simultaneously injecting multiple resins into a multilayer composite armor structure was developed. Called co-injection resin transfer molding, this method provides several benefits in cost and performance of composite

armors. Simultaneous injection of multiple resins, needed for the different composite layers, provides significant cost savings by reducing process steps. It also prevents pollution through both a reduction in process steps and the elimination of secondary bonding of the multiple layers. This method also allows through-thickness reinforcement of a composite layer in the form of aramid stitching. Through-thickness stitching has been shown to improve ballistic and damage-tolerance properties in composite layers. In addition, extensive ballistic testing provided important data on ballistic resistance for various resins including vinyl esters, polyester, toughened epoxies, and urethanes and damage tolerance due to through-thickness stitching.

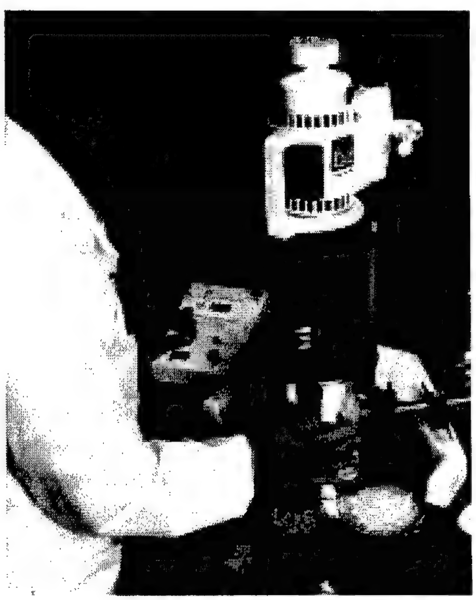
A new electromagnetic repair technique was developed that is well suited for thick-section and integral-armor composites. Induction-based electromagnetic curing and bonding of composites enable localized heating of bondline adhesives and repair resins.

Impact: Development of advanced materials and novel processing techniques will provide multifunctional integral armor systems that will reduce weight and improve survivability of ground vehicles.

New High-Durability Coating

ARL has developed, formulated, patented, and transferred to industry a unique water-dispersible polyurethane coating for Army tactical equipment. The new coating was developed as an alternative for the solvent-based topcoat used in conventional chemical agent resistant coating (CARC) systems. Laboratory tests have demonstrated that the new water-reducible CARC topcoat provides improved durability and excellent compatibility with existing primers and pretreatments. The new coating also yields significantly lower emissions of hazardous air pollutants during application than the current solvent-based coating. Further testing at accelerated exposure sites is in progress to monitor intercoat compatibility, adhesion, corrosion resistance, and topcoat durability. Major paint manufacturers have successfully accomplished scale-up production and several tactical vehicles at the U.S. Army Field Artillery Center at Ft. Sill, Oklahoma, have been sprayed with production lots of the new topcoat.

Impact: The new water-reducible coating will provide a new CARC formulation for weapon systems and other materiel that features improved durability and reduced levels of hazardous air pollutants during application.

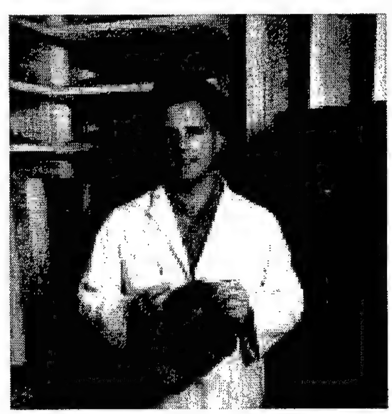


Formulation research for lowvolatile organic compound chemical agent resistant coatings

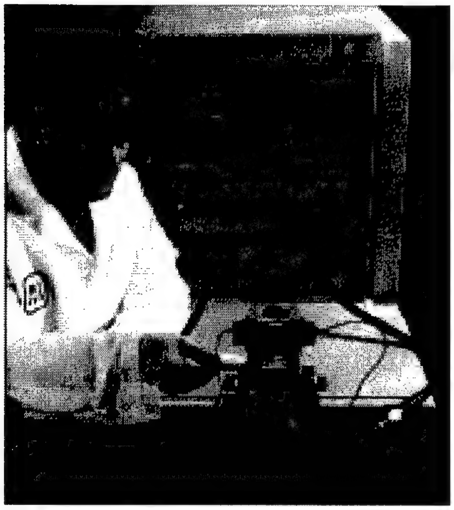
Fast-paced operations in complex terrain will require robust,

Real-Time Situational Awareness

often space-based communications. ARL, in collaboration with its FedLab partners, performs research that provides the fundamental scientific foundation necessary to exploit the technology of the Information Age for Force XXI, Army/Joint Vision 2010, and the Army After Next. ARL's research efforts in the areas of information science, sensors, and human performance are critical components for providing commanders unprecedented real-time situational awareness of the battlefield.



Ferroelectric Phase-Shifter Materials



Ferroelectric phase-shifter material research

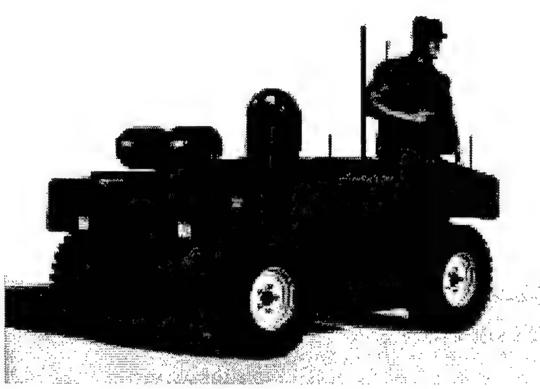
The cost of phased-array antennas is predominantly dependent on the cost of microwave phase shifters. ARL is developing advanced processing methodologies for the production of microwave phase shifters with low-cost, low-power dissipation, voltage-driven ferroelectric composite ceramics. Recent developments include compositional modifications and improved processing procedures for barium-strontium-titanate (BSTO) composites that further reduce the dielectric loss tangent of ceramic phase shifters. The reduction of the loss tangent was accomplished without sacrificing tunability (and, therefore, phase-shifting ability). These inventions will help make ferroelectric materials applicable to reducing the cost, weight, and size of phased-array antennas in Firefinder, Comanche, Communications-on-the-Move, and other Army programs.

Impact: Integration of ferroelectric phase-shifter materials in phased-array antenna systems will reduce the cost and size of electronically steered antennas and enable their application as high-performance alternatives to conventional gimbaled radar systems and other sensor systems.

Robotics and Autonomous Platform Technologies

ARL continues to play a pivotal role in the development and demonstration of technologies that will enable the employment of unmanned ground vehicles in military applications. Major accomplishments were made in support of the Demo III Program—a 4-year program aimed at developing technologies for integration on vehicle platforms and conducting field experiments of these platforms using Army and Marine Corps troops.

Based on design and test validation of an engineering model of the Mobile Detection Assessment Response System (MDARS) vehicle, a North Atlantic Treaty Organization (NATO) Reference Mobility Model (NRMM) was generated for the vehicle, and provided the technical foundation for NRMM prediction of Demo III vehicles. As a result, a new model of the Demo III experimental unmanned vehicle (XUV) was built and is now being used in constructive and virtual simulations at the Mounted Maneuver Battle Lab.



Artist's concept of Demo III experimental unmanned vehicle

A three-dimensional (3-D) dynamic simulation of the base-case XUV was completed and is proving critical for the mobility and sensor stabilization system design for the Demo III vehicles. An assessment of Demo III reconnaissance, surveillance, and target acquisition performance for the forward observer function is nearing completion. In a cooperative effort with the National Institute of Standards and Technology (NIST) and the NASA Jet Propulsion Laboratory, over 10,000 stereo pairs of images were collected, time-tagged, and compared to ladar data for ground truth.

This effort is providing the foundation for mobility sensor selection for the Demo III vehicles.

Impact: Robotics and autonomous platforms will be a force multiplier in providing unmanned ground vehicles that can perform multiple functions in tactical operations.

Advanced Battlefield Visualization Infrastructure

The military needs the ability to visualize terrain, weather, military units, and other events (such as smoke, sensor information, and damage information) to assist commanders at various levels in situational assessment and awareness. Such a capability can be obtained by developing a battlefield information processing infrastructure that addresses scalability and responsiveness in several functional areas. Currently, ARL is integrating 3-D virtual geographic information system (VGIS) software with battle command and control features and course-of-action analysis (COAA) models. ARL has developed software architectures and application programming interfaces (APIs) and introduced enhancements in the extensibility, scalability, and adaptability of the software infrastructure for command and control decision-making applications. In FY98, ARL displayed battlefield weather on the ARL combat information processor (CIP) and VGIS by integrating weather models with the underlying terrain data. Several proof-of-concept demonstrations were presented. As part of its efforts to improve soldier computer interfaces, ARL developed a speech interface with a natural language processor as a front-end model for navigation commands associated with the battlefield visualization infrastructure.

Impact: This program will enhance the commander's situational awareness by providing a window for rapid assessment of the current battle and a tool for visualizing and shaping the next battle.

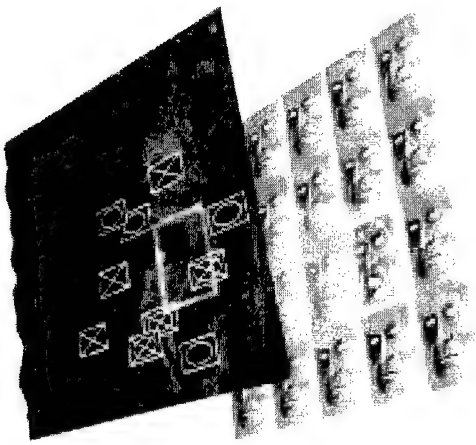
Battlefield Forecast Model Verification and Validation

A tactical Battlescale Forecast Model (BFM) that is operable in the field on Army common hardware and software has been independently validated for use by the Staff Weather Office in support of the tactical Army. The ARL BFM is the heart of the weather forecast capability in the Integrated Meteorological System (IMETS). A plan to validate the current version of BFM, Block II, V 1.2, was jointly developed in October 1997 with participation from the U.S. Army Intelligence Center at Fort Huachuca, AZ; the Air Force Weather Agency; and members of ARL. Variables to be validated included the U and V wind components, wind speed, temperature, and the dew point temperature at multiple layers on a horizontal grid. In FY98, the Air Force Weather Director of Army Weather Policy informed the Army that new Air Force policy will be that no numerical weather prediction models will be run in the field, which included BFM. The Air Force intends to broadcast all forecast weather data grids from central hub sites to support Air Force forecasters operating IMETS in the field. The Air Force has declared that the MM5 forecast model will be the model run at the central hub. Verification efforts between the Air Force and ARL have ceased. As soon as MM5 data are routinely received from the Air Force, BFM will be removed as a forecasting tool from the IMETS system.

Tactical Operations Center Intelligent System

The introduction of computers, computer-controlled devices and platforms, and high-speed communications equipment has led to an increased intensity of information on the battlefield. The increasing intensity and dynamics of the battlefield motivated this research effort. At the same time, there is a drive to decrease the size of the Tactical Opera-

tion Center staff. These forces are necessitating the automation of the low-level reasoning tasks that are key to developing situational awareness. This ARL research focuses on collaborative software agents for enhancing situational awareness among Tactical Operation Centers.



Collaborative software agents will enhance a commander's situational awareness

Several independent thrusts are underway that, when integrated, will be capable of supporting Tactical Operation Centers at multiple echelons. Software agent scalability will be demonstrated in the battlefield visualization application. Additionally, the critical fusion of local and global views will also be shown on a commander's software platform. In FY98, software agent infrastructure and agent applications in the areas of defensive information warfare and focus of attention have been designed. Additionally, initial designs for communications visualization, and agent human-computer interaction have been completed. One of the key elements of the evolving software agent architecture is the IMPACT server, which provides features crucial to the autonomous behavior of the agents.

Several applications have been developed and demonstrated using this server, including alert agents, which watch for desired events and provide notice to the user; planning agents, which assist the staff in planning operations; and high-level physical agent control. ARL has commenced modification of the legacy battlefield visualization software to build architectures appropriate to the effective use of software agents. This will simplify future integration of the agent architecture into the visualization system.

Impact: By providing the enabling technology, results from this program will increase the mental agility and mobility of the commander. The resulting software will be used to support the operational concept development carried out by TRADOC Battle Labs and the AAN process.

Colorado State University: Center for Geosciences/Atmospheric Research

CG/AR is a cooperative effort between the Army, Air Force, and Naval research laboratories and the Colorado State University, Cooperative Institute for Research in the Atmosphere. The purpose of CG/AR is to transition environmental research and development products into the military services to support tactical meteorological software development. This effort includes initiatives in the areas of hydrological modeling, clouds, satellite remote sensing, and mesoscale model development. These products will enhance future tactical capabilities to effectively predict and mitigate the adverse impacts of weather on operations.

Impact: Products developed under this collaborative research effort will enhance future tactical capabilities to effectively predict and mitigate the adverse impacts of weather on operations.

Acoustics and Electro-Optics Propagation

Based on a need for a consistent physical description for optical absorption, scattering, radiative transfer, and turbulence in the atmosphere and the new simulation capability requirements, a new suite of electro-optics–infrared (EO-IR) models named the Weather and Atmospheric Visualization Effects for Simulation (WAVES) is being developed at ARL. Research in acoustics and electro-optic propagation in the atmosphere adds significant capability to situational awareness and sensor performance information. The basic and applied research is delivered to a variety of customers throughout DoD. The increasing inventory of acoustic sensors in the Army drives the need to quantify the impact of the atmosphere on acoustic propagation. The acoustic propagation modeling at ARL comprises a hierarchy of acoustic models—SCAFFIP, SCAPE, BASE, and ABFA—that describe the impact of the atmosphere on acoustic energy by accounting for refraction, diffraction, turbulence (scattering), and ducting. Today these acoustic models augment acoustic automatic target recognition (ATR) by removing atmospheric effects from target signatures, augmenting the targeting of cruise missiles, and providing decision tools for the commander.

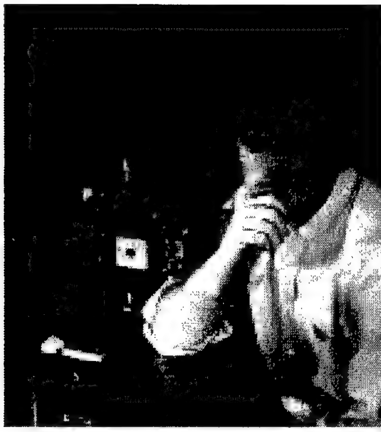
Impact: This research effort will continue to deliver technology improvements to the methods of characterizing meteorological parameters that have an impact on situational awareness and sensor performance.

Dual-Band Quantum-Well Infrared Photodetector

For the Army of the future to own the battlefield, it needs complete battlefield visualization; thus, sensors must be able to see through a variety of environments and conditions. In the dual-band quantum-well infrared photodetector (QWIP) focal plane array (FPA) program, mid-wave and long-wave detectors are combined on one wafer to provide operation in conditions such as dust and smoke. In FY98, ARL designed dual-color focal QWIP pixels that improved performance in an FPA. The obstacles overcame included developing schema for coupling incident light into the quantum wells. QWIP wafers were produced and used to make test arrays. These arrays showed detection response in each band equivalent to a single band detector.

Impact: This technology will enable the development of 3rd Generation forward-looking infrared (FLIR) detectors.

Researchers testing a single-pixel 15-μm infrared detector chip



Battlefield Decision Making

One of ARL's missions is to ensure that soldiers can operate with maximum effectiveness on the high-technology battlefield of the Army After Next.

Under the hostile and highly stressful conditions of the battlefield, individual soldiers, crews, units, and staff must operate ever more complex and technically sophisticated systems. ARL pursues greater understanding of human performance characteristics and limits—and shares those findings within the Army and with industry—in its efforts to optimize soldier effectiveness and soldier-machine interactions and to ensure that future system designs will enable our soldiers to achieve maximum performance. ARL's efforts will significantly improve the battlefield soldier's ability to absorb information and make decisions.

Wargaming and Simulation of Real-Time Battlefield Data and Information

The military is in the process of merging modeling and simulation with the acquisition process. Called SMART (Simulation and Modeling for Acquisition, Requirements, and Training), it is the process the Army has embraced to bring modeling and simulation to bear on the entire acquisition process. ARL is involved in the SMART process, and brings its expertise in the area of data fusion, course-of-action analysis, and wargaming and simulation to the problems of integrating real-time battlefield data and computer simulation. Currently, ARL is investigating wargaming and simulations based on real-time data and information obtained from various battlefield information sources and the advanced battlefield information processing infrastructure. In FY98, ARL studied differential and statistical methods to develop and analyze courses of action and possible integration with the modular semiautomated forces (ModSAF) software. The high-level architecture (HLA) has been studied for the development of appropriate object models and interoperability with the real-time battlefield infrastructure.

Virtual sand table

Impact: This program will enhance the commander's situational awareness by merging real-time battlefield information (ground truth) with wargaming and simulation forecasting for reliable, real-time monitoring of the battle.

Prototype Atmospheric Profiler

The Meteorological Measurement Set-Profiler (MMS-P) is a major product improvement to the current MMS. This new profiler system improves upon the current MMS by

- reducing the required manpower by 33 percent,
- reducing operating costs by $16M per year for all 82 units,
- increasing data collection frequency by a factor of 12, and
- improving medium-range indirect fire accuracy by 40 percent.

The system incorporates, as primary remote measurement instruments, a wind-profiling radar and a passive microwave radiometer for temperature profiles. A new Semiautomated Meteorological Station (SMS) now in the Army inventory provides surface measurements. Atmospheric profiles from the ground-based systems are combined with soundings generated from meteorological satellite data to form merged soundings that can extend from the surface to about 30 km. The current prototype MMS-P also has a global positioning system (GPS) rawinsonde capability to provide comparison data and to provide a substitute for the satellite soundings if needed. The onboard Battlescale Forecast Model (BFM) consists of a mesoscale model with interface software that will use the local profiles and other data (e.g., the Navy Operational Global Atmospheric Prediction System (NOGAPS)) to generate a 3-D analysis over an area of up to 500 x 500 km, as well as forecasts for several hours. The entire system fits in a shelter carried by a HMMWV plus a high mobility trailer (HMT) for the wind radar. A separate vehicle tows a *silent* generator.

Impact: This technology improvement will enable artillery units to employ accurate and timely meteorological data to enhance the effectiveness of artillery munitions.

Collaborative Platform Intelligent System

Technology advances over the last decade have laid the foundation for significant change in the character of warfare. The massive application of soldiers and brute force is giving way to intelligent application of technology. The strategy is to gain as much information about the enemy as possible before committing the main battle forces. This tactic is more pertinent in urban encounters where the intensity of combat is high and collateral casualties can cause missions to be abandoned for nonmilitary reasons. The reconnaissance, surveillance, and target acquisition (RSTA) of both human and vehicle targets are essential precursors to planning any injection of forces into a local theater. The discovery of the presence and extent of chemical and biological agents is critical to mission success and the safety of military personnel.

Research on collaborative platforms is essential to execute these tasks without introducing people. Software agents give the platforms intelligent behavior and enable them to operate autonomously with only marginal and high-level remote instructions. Equipping the platforms with other capabilities, such as multiaspect RSTA, microscale weather prediction, communications on the move, planning and visualization, and microchemical/microbiological sensing makes them very effective against adversaries. In FY98, the Collaborative Platform Intelligent Systems project made progress in a number of areas. Several new concepts related to mother ships and logistics were generated. The RSTA design for a small urban robot was tested and a report was prepared and included as part of a Jet Propulsion Laboratory (JPL) document intended for DARPA. Additionally, ARL's visualization and planning software was used in the Office of the Secretary of Defense (OSD) Demo III program to positively benefit that program.

Impact: This program will enhance the commander's situational awareness by providing autonomous cooperative intelligent systems for reconnaissance, surveillance, target acquisition, and the detection of chemical and biological agents in a theater of operation. These systems will enable commanders to obtain real-time high-resolution information on contaminated or dangerous environments where it is unwise to send a soldier.

Center for Applied Remote Sensing in Agriculture, Meteorology, and Environment

CARSAME is a cooperative effort between ARL, New Mexico State University, and the Directorate of Environment at Fort Bliss, TX. The purpose of CARSAME is to advance the Earth Observation (EO) data as an essential element of the sustainable development of arid lands. One of the applications being developed includes the use of EO-based surface temperature to derive degree-day and accumulated degree-day maps. These can be used in a variety of programs such as Integrated Post Management (insect and plant phenology) or Water Resource Management as well as in Fire Hazard Prediction, Detection, and Damage Assessment.

Impact: This research effort will provide multiple meteorological data sets to be used in the development of advanced forecasting and prediction models.

Multidomain Smart Sensor Demonstration

The MDSS effort is the key electro-optic component of the technology solutions for battlefield visualization. The goal of the MDSS program is to develop a smart sensor prototype that combines passive large-area staring, mid-wave, and long-wave infrared sensors with an active ladar sensor. By the development of signal and image processing

techniques for the outputs from these multiple sensors, great improvements over current target detection sensors and algorithms will be realized. In FY98, ARL demonstrated stand-alone boresighted sensors. The outputs from the sensors were electronically fused, allowing improved detection through the passive IR sensors and recognition through the ladar sensor. Significant improvements compared to the 2nd Generation FLIR (a passive signal band sensor) were demonstrated.

Impact: This technology supports the 3rd Generation FLIR program through improved detectors and signal processing and ladar.

Modular Neural Network Automatic Target Recognition Algorithm

Automatic target recognition (ATR) is a cornerstone of the Army's goal of unprecedented battlefield visualization. ATR will not only tell the operator what targets are detected in the battlefield, but it also will significantly reduce the soldier's workload through reducing soldier stress and errors. This project is an important step in the evolution of ATR algorithms. Its goal is to employ a neural network algorithm for target detection and clutter rejection, using techniques proven to be the most successful for target identification. In FY98, the modular neural network ATR algorithm improved performance by a factor of 2 in terms of target identification performance (M60A1 and T72 tanks) when compared to the model-based algorithm using a night vision and electronic sensor 2nd Generation FLIR database.

Impact: This project translates into improved target acquisition performance on the Comanche helicopter database, and significantly reduced computational complexity.

Adaptive Target Detection

The detection of stationary targets with a real-aperture fire-control radar at low depression angles is a difficult challenge, because the signal-to-clutter ratios are low and because clutter environments vary greatly throughout the world. Since current stationary target indicator algorithms are trained on clutter and target-in-clutter data for each site, algorithm performance may be degraded if a new clutter or target environment is encountered. ARL's goal is to develop an adaptive-detection algorithm that autonomously adjusts the decision surfaces of a target/clutter discriminator to changing clutter backgrounds *on the fly*. In FY98, ARL developed a Longbow compatible data set, and trained and tested the Longbow detection algorithms, as well as adaptive target detection algorithms. ARL demonstrated the capability of an adaptive detection algorithm by training on data from three sites and then testing at the trained sites and at a site that was not included in training. At the sites included in training, the adaptive-detection system achieved site-specific performance without the need for cueing. Although the adaptive system had never seen the new site, it adapted to the incoming data and achieved site-specific performance.

Impact: Through this technology the force projection Army will achieve quick-reaction worldwide deployability, enabling improved lethality and heightened platform survivability.

Cognitive Engineering of the Digital Battlefield

Starting in FY98, ARL undertook a multiyear science and technology objective (STO) to provide the Army with a greater understanding of the information and decision-making demands of tactical battle command (battalion through corps). Drawing insights from the fields of cognitive psychology, organizational psychology, management science, and

complexity theory, this research focuses on how commanders and other key decision-makers adapt under stress to ambiguous and changing battlefield environments. Parameters considered in this process include the nature and level of staff experience, the design and integration of digital information systems, and the organization of functional responsibilities within the Tactical Operations Center.

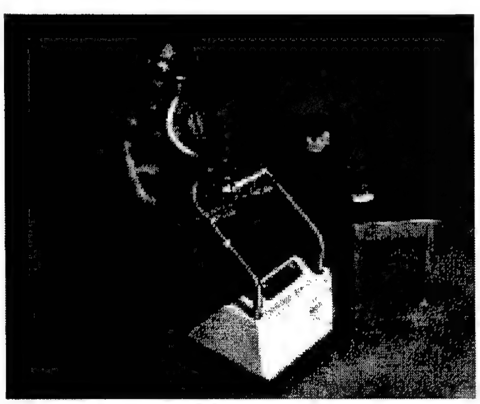
Working in close partnership with TRADOC Battle Labs, ARL researchers are developing relevant process models and performance metrics for assessing the cognitive and organizational components of battle command under realistic conditions. FY98 assessments during the Division XXI Advanced Warfighting Experiment, Prairie Warrior 98, and two battle command reengineering experiments at Ft. Knox, KY, allowed researchers to identify a number of critical performance issues related to naturalistic decision-making, situational *sensemaking*, and battle staff training. From this work, ARL provided the TRADOC Program Integration Office with a set of functional requirements for future versions of the Army Battle Command System (ABCS).

Research for the next few years will focus on the Army's development of Strike Force with its expanded mission demands and requirement for adaptable, rapidly deployable battle command operations. Looking further into the future, ARL researchers will be collaborating with the Defense Advanced Research Project Agency (DARPA) (Command Post of the Future) and Communications-Electronics Command (CECOM) (Command Post XXI Advanced Technology Demonstration) to examine the role of advanced display and decision-aiding technologies.

Impact: As the Army moves beyond Force XXI to AAN, this research program will provide the critical linkage among materiel, soldier, training, and organizational developments for digitized battle command.

Various Effects on Message Intelligibility for the Dismounted Soldier

Three-dimensional audio technology can improve the intelligibility and information transfer of incoming radio messages by perceptually separating the sound sources in space. Previous research on helicopter pilots and armor crewmen has quantified the benefit of 3-D audio, but none of the research had quantified the extent to which 3-D audio technology affects the ability of the dismounted soldier to understand speech messages while challenged by varying degrees of physical activity in a complex listening environment.



Test of soldier listening for audio cues while physically stressed

The results indicate that 3-D audio technology enhances the ability of the dismounted soldier to understand and respond to speech communications from multiple channels. Soldiers using 3-D audio were able to correctly identify almost 50 percent more radio messages than those using monaural displays, and the response time to message identification was significantly shorter with 3-D auditory displays. Three-dimensional audio was effective because it provided perceptual cues necessary for the soldier to selectively attend to the different messages.

Impact: The data from this research support several programs, most notably Land Warrior. Application of the

research is being extended to the Virtual Cockpit Optimization Program (VCOP) and to the Tank and Automotive Research, Development and Engineering Center (TARDEC) Vetronics test bed to improve crew performance in advanced air and land combat vehicles.

Soldier Performance on Slippery Surfaces

Soldiers traversing the "mud" course

Most research efforts regarding cognitive and physiological performance have concentrated on quantifying these two types of performance separately. However, emerging soldier systems such as Land Warrior concurrently require both high cognitive and physiological workload. ARL's pilot study, supported by our research partner, the Army Research Institute of Environmental Medicine, examined the interaction between these two types of performance. In this study, soldiers performed cognitive tasks while carrying two different loads (50 lb and 81 lb) over three different types of terrain—blacktop road, loose sand, and mud. The physiological performance of the soldiers in this study was as expected, while performance on the cognitive tasks was not statistically significant.

The results of this study lead to questions that will require additional research to answer: If the march continues for several hours, how is performance on the monitoring task affected? How would combinations of other cognitive measures (decision-making tasks and multiple tasks that must be done simultaneously) and a more strenuous physical component (a variety of speeds, grades, and unpredictable terrain) affect performance?

Impact: Results from these studies will quantify soldiers' cognitive and perceptual abilities while performing physical work, ensuring that new systems are designed to maximize total soldier-system performance.

Task and Workload Modeling for Cognitive Engineering

An analysis of Desert Storm activities resulted in requests in 1994 from the U.S. Army Armor Center to the Command and Control Modeling Team at ARL to develop task and workload models of various personnel, vehicle, and equipment concepts for a Heavy Maneuver Battalion Tactical Operations Center (TOC). These models progressed from a totally analog TOC to a partially digital TOC to a completely digital TOC. The task and workload models assess the amount of workload experienced, measured by task completion time, for each TOC operator, as they collectively work to establish effective command and control over the battlefield.

Modifications to these models in FY98 resulted in the capability to apply degradation factors that include fatigue, noise, and vibration to create a more accurate assessment of command and control functions in moving vehicles. These second generation task workload models are currently slated for use during FY99 to assist the Operational Test

Researchers viewing TOC and command section progress during "digitized" battle

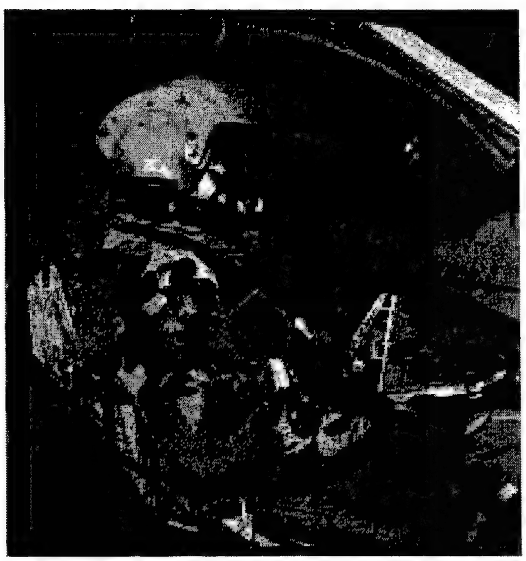
and Evaluation Command (OPTEC) as it attempts to address questions dealing with the capabilities of command staffs to perform their missions within a mobile working environment.

Future research will focus on further developing degradation factors to enable the task workload models to quantify the effects of changing environments, personnel, and equipment on conceptual TOC designs.

Impact: These models assist force developers in their understanding of the complexities that tomorrow's commanders and staffs will face on the future digital battlefield. The methodologies are applicable to any command echelon or task-based process that is measured by task-completion time.

Enhanced Performance Degradation Modeling in IMPRINT

This FY98 effort built on the existing capability in the Improved Performance Research Integration Tool (IMPRINT) by extending the set of available performance stressors. The current set of stressors in IMPRINT—heat, cold, noise, protective clothing, and sleep deprivation—is an important and unique capability, but falls short in modeling the complete set of battlefield stressors.



Modeling can help prevent degraded performance because of clothing and equipment encumbrances

Through a review and critique of research conducted by the Army and by other government and academic programs, a set of candidate stressors was identified. Vibration; exposure to nuclear, biological, and chemical contaminants; and the interaction of sleep deprivation and circadian rhythm are a few of the stressors that could be modeled in IMPRINT.

A related effort, funded by the Air Warrior program, developed a set of specific clothing and equipment stressors. Detailed, item-by-item performance degradation factors were developed using data gathered from experienced aviators as well as integrated product team members responsible for overseeing the development of the future Air Warrior ensembles and protective equipment. For the first time, collaboration with CASTFOREM modelers at the TRADOC Analysis Center at White Sands Missile Range allowed the inclusion of Apache gunner performance data for current and predicted future stressed environments in a force-on-force model.

Continued collaboration with modelers and researchers of performance in extreme environments will ensure that a comprehensive set of performance degradation factors is made available through the IMPRINT modeling and analysis tool.

Impact: Modeling human performance—both *typical* performance and performance in extreme or stressful environments—is an essential element of Simulation-Based Acquisition (SBA). This effort provides a unique tool for concept and materiel developers to analyze and refine system requirements.

Information Assurance

With the Army becoming more and more dependent on computers, high-speed digital communications, and satellite links on the battlefield and in the office, ARL is pursuing technologies and procedures to provide a secure, reliable information infrastructure. Computer scientists and engineers are developing distribution capabilities to exploit processing power within narrow communication bandwidths, and they are designing secure mobile networks to enable commanders and deployed units to access secure information/data on the battlefield. At the same time, the information community has launched coordinated efforts with the intelligence community to protect these capabilities and networks and to detect and deter unfriendly disruptions and intrusions. ARL is helping to solve the defensive information warfare problem.

Command, Control, Communications, Computer, and Intelligence (C^4I) Systems

ARL continued its support to the Project Manager for the Army Tactical Command and Control System (PM ATCCS) on the Maneuver Control System (MCS) by providing technical data in the electronic warfare (EW) and information operations (IO) threat areas as part of a soldier survivability (SSv) parameters assessment list analysis. This SSv was provided as input to the MANPRINT assessment that was requested by the PM in support of the MCS Milestone III (MSIII) in early FY99. Also, at the request of the Operational Test and Evaluation Command (OPTEC) Evaluation and Analysis Center (EAC), ARL conducted a quick-look IO experiment on the MCS that was at Fort Hood, TX, for its initial operational test and evaluation. The collected data were provided to the EAC and the PM for evaluation. As a follow-on to the Fort Hood test, ARL initiated an experimentation plan for continued IO analysis of MCS in the Communications and Electronics Command (CECOM) Digital Integration Laboratory (DIL). This experimentation was led by ARL with support from the CECOM Command and Control (C^2) Protect Team. The data from this follow-on experiment will also feed the MSIII decision review. ARL continued IO analysis efforts on the Mobile Subscriber Equipment system to determine the threat due to rf attack. ARL, along with CECOM's Intelligence and Information Warfare Directorate (I^2WD), prepared a briefing to be given to the PM for the Warfighter Network-Terrestrial (PM WIN-T) to determine the need to pursue further analysis/ experimentation due to the system improvements in the communications and switch areas. ARL, as part of the CECOM C^2 Protect Team, provided the PM for the Tactical Radio Communication Systems (PM TRCS) and the PM for Appliqué with the results of the Force XXI Battle Command Brigade and Below field test at Fort Huachuca, AZ, in June 1998. Information on software fixes and operational procedures was provided so that the developer could correct future releases of the software for these systems.

Impact: ARL analyses provided critical early insight into the vulnerabilities of the systems that are necessary to the fielding of the First Digitized Division, the Army's top priority. Without these analyses, OPTEC, the Program Executive Office for Command, Control, and Communication Systems (PEO C^3S), and the Director for Information Systems Command, Control, Communications, and Computers ($DISC^4$) would be unable to definitively answer congressional inquiries regarding the vulnerabilities associated with the fielding of the Army's premiere fighting force for the twenty-first century.

Wireless Multi-Hop Soldier LAN

The Army requires the capability to extend simultaneous data, voice, image, and video transfer systems to the soldier and/or platform with acceptable levels of throughput, range, capacity, information quality, security, and precedence in real- or near-real-time. Wireless digital communications are essential to support the highly mobile forces of the Army. ARL's research in methods to provide high-capacity wireless communications to dismounted soldiers has focused on technologies for low-power, multi-hop, and hand-held or wearable communication systems and networks for the individual soldier. In FY98, ARL demonstrated communications at 1 Mbps to multiple nodes at ranges up to 200 m. Range extension and multi-hop development are in progress.

Impact: This research will provide wireless digital communications in an integrated architecture to support mobile warfighters.

Defensive Information Warfare

Future military communication systems will consist, in part, of mobile communication networks that will be massive in scope. These networks will be subject to both physical and information warfare attack and may undergo radical reorganization during combat. Accordingly, their network control infrastructures must be adaptive, robust, survivable, scalable, and well suited to providing comprehensive battlefield awareness and near-real-time command and control (C^2) communications. Owing to the high sensitivity of C^2 communications, this infrastructure must also be secure. This program focuses on providing survivable and secure tactical networks and information warfare protection technologies. During FY98, ARL made significant progress in the areas of Mobile Ad Hoc Networking (MANET); authentication architectures; and public shared key generation, information hiding techniques, and approximate message authentication.

Mobile ad hoc networking

Accomplishments include the following:

- Devised a lightweight, dynamic multicast routing algorithm for MANETs.
- Devised a new shared key generation scheme that permits mistrusting parties to cooperatively generate a shared key for group multicast communications.
- Developed an architecture that is essential to support reliable routing in an interdependant mobile network.
- Demonstrated that spread spectrum image steganography can hide messages of significant length (5 KB or more) in ordinary images.
- Devised an Approximate Message Authentication Code (AMAC) that is much more consistent with the high bit-error-rate wireless tactical battlefield environment.

Impact: This research will provide protection of battlefield information and tactical networks by ensuring their availability, integrity, authentication, confidentiality, and nonrepudiation.

Technical Support Initiatives

FedLab

ARL seeks out the best ideas and research and tries to put them to work for the soldier. ARL established the FedLab in 1996, entering into cooperative agreements to establish consortia of industry and university partners in three areas—Advanced Sensors, Advanced Displays, and Advanced Telecommunications and Information Distribution. Through FedLab, ARL is tapping the leading-edge expertise and facilities of universities and private industry.

FedLab collaboration

This past year saw notable progress in the development of collaborative research among the three consortia. A series of joint workshops was conducted that focused on data and image compression research. This is a critical area for the future Army given the urgent need to disseminate imagery over limited bandwidth data links without corrupting or losing key information. Researchers from all three consortia cooperated, conducting joint research aimed at coupling image compression with target recognition techniques. In a second area, each of the consortia is conducting collaborative research in networked microsensors, including work in sensors, signal processing, communications links, information distribution, and the display of data and information derived from distributed sensor networks.

One of the key features of FedLab is its ability to redirect or refocus research quickly and efficiently when the need arises. For example, the Advanced Sensors Consortium added two new members in response to the need to develop a research thrust in networked microsensors. Rather than ramping up slowly within the existing partners, the consortium decided to reallocate funding to add the University of California at Los Angeles (UCLA) and Rockwell as associate members of the consortium. By *going where the expertise is*, the consortium enabled the Army to take advantage of existing expertise and to leverage ongoing research at the associate institutions that was being sponsored by other DoD agencies. In a second example, the Advanced Telecommunications and Information Distribution Consortium added Southern Methodist University to its membership to supplement the multimedia research program.

During the fall 1998, ARL leadership prepared a proposal to expand these external partnerships by taking advantage of language in the FY99 National Defense Authorization Act to add FedLab-type arrangements. In its proposal for participation in the pilot program, ARL suggested three new agreements: robotics for the battlefield, fuel-efficiency for vehicles, and information assurance.

High-Performance Computing

The goal of the High-Performance Computing initiative is to provide ARL and the Army RDT&E community with up-to-date high-performance computing capabilities, unclassified as well as classified.

High-performance computing assets

As part of the DoD High-Performance Computing Modernization Program (HPCMP), ARL was designated a Major Shared Resource Center (MSRC), with system integration contract awarded to E-Systems in August 1996. The ARL MSRC is interconnected to the other three DoD MSRCs, to many distributed HPC assets, and to the DoD S&T user community through the Defense Research and Engineering Network (DREN). To support optimal use of HPC resources for defense critical programs, the HPCMP contains the Program Environment and Training (PET) and the Common HPC Software Support Initiative (CHSSI). The purpose of the PET program is to develop and transfer state-of-the-art HPC software technology to the DoD user community. CHSSI is directed to advance scalable applications software in the ten computational technology areas: structural mechanics, fluid mechanics, chemistry and material science, electromagnetics and acoustics, climate/weather/ocean modeling, signal/image processing, forces modeling and simulation/C4I, environmental quality, electronics and nanoelectronics, and integrated modeling and test environments. ARL is one of the major participants in this initiative.

The MSRC's raw computing power more than doubled in FY98 through major hardware acquisitions. The MSRC will double the processing power of the unclassified T90, bringing the number of processors from 8 to 16 and the memory from 512 MW to 1 GW. A new 128-node Origin 2000 with the R10K processors was installed early in 1998 and a second 128-node Origin 2000 with the new R12K was to be installed in the summer 1998. The classified Origin 2000 will undergo an upgrade to double its processing power, bringing it to 128 CPUs.

3-D scientific visualization

The MSRC is working toward extending its computing capabilities and services to classified users and the test and evaluation community. The MSRC increased its effort to establish memorandums of understanding with remote classified users and to ensure that network support is made available to these communities. The ARL MSRC, having the DoD lead for the Integration Modeling and Testing Computational Technology Area, is continuing its close interaction with the Test and Evaluation Command (TECOM) to ensure that the MSRC is responsive to the Army test and evaluation community's real-time and data storage needs.

The Programming Environment and Training component of the MSRC made strong inroads in FY97 in the areas of training, Historically Black Colleges and Universities (HBCU) involvement, and development of programming tools in support of ARL's S&T community. It committed to considerably increase these services in FY98. The ARL MSRC PET program staff is working closely with Clark Atlanta and Jackson State universities to ensure HBCU students are receiving training in computational focus areas such as signal image processing and distributed parallel storage systems, while at the same time engaging HBCU faculty in Army-related projects. The ARL MSRC program is also initiating and will conduct collaborative efforts with its lead academic institutions: the National Center for Supercomputing Applications (NCSA), Rice University, Mississippi State University, and Ohio State University. The emphasis of the collaborative activities will be on programming technology development and transfer and associated training.

The Advanced High-Performance Computing Research Center (AHPCRC) is the Army's research center for the application of high-performance computing to Army technology issues. The AHPCRC operates under the cognizance of ARL and is engaged in collaborative research projects with ARL, Corp of Engineers Waterways Experimental Station (CEWES), and the Research, Development and Engineering Centers (RDECs). It also provides training and educational programs designed to support the Army leadership in the application of HPC to defense-critical technology issues. The AHPCRC is planning a major hardware acquisition that will allow it to continue to effectively serve the Army and DoD users as a Distributed Center in the DoD HPC Modernization Program. The AHPCRC will continue to focus its research on high-performance computing and apply the developed technologies to simulations of systems or processes that are of high importance to ARL and the Army.

Army After Next

In 1995, the Chief of Staff of the Army charged TRADOC to

> *define what we want in the Army After Next [AAN] so that Force XXI does not get disjointed from the long-term vision, and we focus our R&D efforts.*

As the Army's corporate laboratory, ARL is responsible for reaching throughout the Army Materiel Command (AMC) and the national science and technology community to provide technology support to the AAN Project Office in TRADOC. The goal of AAN is that it will provide the vision for the future Army with the intellectual underpinnings to make it credible. This will lead to the sufficient redistribution of resources in DoD to build the twenty-first century AAN.

The overarching goals are to leverage AAN studies to strengthen Army S&T, establish a strong partnership with the TRADOC AAN Project Office, take a customer-focused approach, and build a team with the Army Research Office (ARO) and Secretary of the Army for Research, Development, and Acquisition (SARDA) and involve the wider S&T community. The AAN Project Office offers a unique opportunity for the Army to change from the sequential way of weapon systems research, development, and acquisition (RD&A) of the past to a more efficient process. The AAN process enables TRADOC and the RD&A community to collaborate early in the conceptualization phase, rather than late in the development stage. Together, the warfighters and the technologists can work all parts of the problem simultaneously—exploring changes in military arts, conceptualizing

systems to achieve advanced strategic and tactical capabilities, identifying critical enabling technologies, and developing technology investment strategies. The synergy that will occur from this collaborative approach will result in truly revolutionary advances in our future military capability. This process has already achieved dynamic results. ARL was instrumental in developing integrated idea teams (IITs) to transform notional system concepts developed to provide the strategic, operational, and tactical capabilities being explored by AAN.

The Fires ITT has successfully brought together 125 members of the national RD&A community, the Army operational community, and the Joint Services. The Fires IIT process organized participants into a team to investigate AAN-era Fires concepts that support capability requirements and notional system descriptions for the 2025 timeframe and beyond. In addition, the Fires IIT was tasked with identifying enabling technologies for each concept and to prioritize key technologies.

In June 1998, AMC/ARL sponsored a Fuel-Efficient Army After Next workshop in Cleveland. This workshop initiated the first phase of a three-month fuel-efficiency study for AAN. Scientists, engineers, and warfighters met to discuss and develop an approach for making a positive, concerted effort to reduce the logistics burden presented by the Army's need for fuel in the 2025 timeframe.

During the first week of the 1998 Spring AAN Wargame, the Technology Cell conducted a Nonlethal Effects workshop. Fifteen experts from a variety of government agencies participated. The goal of the workshop was to develop and prioritize concepts and capabilities that will provide a full range of nonlethal effects—including antipersonnel, antimateriel, and anti-information systems and methodologies—for military operations in the 2025 timeframe.

ARL will continue toward its goal of seeking new technologies to support AAN. With its FedLab partners, ARL will be able to enhance its focus on meeting its grand challenges as it works toward this goal.

Management Initiatives

Business Process Reengineering and Automation

ARL continues to provide faster and more efficient functional support with a dramatically smaller support staff. Twin objectives are to streamline business processes and conduct internal business over the ARL intranet. Continuing the development of advanced enterprise-wide computing systems will enable the strategic use of information at all sites and levels within the lab. The goal is to use information technology to locally customize software to meet the specific needs of each directorate and center, while gaining the cost benefits of centralization.

In FY98, ARL began developing the architecture for an advanced enterprise-wide computing system that defines the integration of a corporate intranet, a suite of business software applications, and corporate data warehouse. During the year, ARL implemented ARLinside, the Corporate Intranet (versions 3, 4, and 5) and delivered 10 Corporate Business Application Software System (C-BASS) Web-accessible components. C-BASS systems implemented and deployed ARL-wide included BuyIt V1.3 for procurement workflow, PDQuik V1.2 for personnel description generation, and SlideShow V2.0 for sharing corporate presentations. Travel V1.1 was implemented and deployed for use at Aberdeen Proving Ground (APG), MD. The first version of the Corporate Data Warehouse, an FY98 initiative, was developed, including a Data Warehouse Model V1.0 and executive information systems for three prototype subject data marts.

In FY97, ARL committed to a single development and messaging environment, Lotus Domino/Notes. Following the initial rollout, ARL extended Notes availability throughout the lab in FY98, to include adding multiple Domino/Notes servers at each of the major sites, Adelphi Laboratory Center (ALC), APG, and White Sands Missile Range (WSMR).

Another major effort is related to computer security. Current automated checking facilities will be extended to all sites, and various computer security initiatives that started at ALC will be extended to APG and WSMR. In addition, computer security measures (Kerberos/Secure ID) developed at APG will be extended to ALC and WSMR.

The ARL Library System operates from ARL's two main sites, APG and ALC, and is actively participating in the corporate information technology and services integration. ARL established a Corporate Library Advisory Committee in FY97 to advise lab management on future needs and requirements for library and information services. In compliance with the investment strategy document submitted by the advisory committee in January 1998, the ARL Technical Library has contracted for delivery of a variety of electronic journals and database and information services to the desktop of all authorized ARL employees.

Consolidation

The 1991 Base Realignment and Closure (BRAC 91) action mandated that ARL missions completed in Watertown, MA; White Sands Missile Range, NM; Woodbridge and Fort Belvoir, VA; and Fort Monmouth, NJ, be consolidated at ALC and APG. As a result, ARL started construction of two major state-of-the-art laboratories and several smaller facilities to accommodate the affected missions. In addition, to meet mission realignment goals, ARL undertook construction of several supplemental facilities.

In July 1997, ARL dedicated the new Rodman Materials Research Laboratory at APG. Construction continues at ALC on the Physical Sciences Facility, with completion expected by summer 1999. This new facility will house the staff of the Sensors and Electron Devices Directorate (SEDD), the ALC component of the Corporate Information and Computing Directorate (CICD), and a tenant organization with similar or complementary research and development (R&D) capabilities. Phase-in moves will start in spring 1999, with SEDD personnel relocating from temporary sites, such as those in Maryland at Shady Grove, the University of Maryland, and the Johns Hopkins Applied Physics Laboratory, as well as Rutgers University in New Jersey, and *swing* space at ALC.

This complex includes 78,000 net square feet (NSF) of general laboratory space, 6,400 NSF of clean laboratories, and 90,000 NSF of scientist and engineer (S&E) offices, with 100,650 NSF of mechanical and electrical space. Included is an R&D computer center. This $6.7M military construction, U.S. Army project, will provide a central connecting point for ALC to the high-performance and simulation computers at APG.

Although there have been support tenants at ALC for many years, during FY98, ARL conducted an extensive search for R&D organizations to work with the ARL scientists and engineers. This partnering is expected to bring a synergy between the scientists resulting in a product that cannot only better the Army but can also be transferred to industry. In July 1998, ARL entered into an Interservice Support Agreement with the Corps of Engineers for the Laboratory of Telecommunications Sciences (LTS). ARL provides base support and other administrative services in return for financial reimbursement. The LTS complements ARL work in the information assurance arena.

In October 1997, ARL dedicated its new Electromagnetic Research Facility at ALC. Previously known as the Scale Model Laboratory, it is designed as an electromagnetically transparent scale model experimentation facility and is constructed primarily of wood to avoid electromagnetic reflections. Personnel relocating from Woodbridge are using this facility for their research. Potential uses include support to the ultrawideband radar and high-power microwave programs.

ARL addressed its parking needs by providing new parking in the building 400 area and at the Whittaker Building and by expanding existing parking at several locations. A new parking area between the front gate and the Harry Diamond building was completed ahead of schedule in January 1998.

Shady Grove

Until the Physical Sciences Facility at ALC is complete, SEDD personnel who moved from Fort Monmouth and Fort Belvoir are being housed at a laboratory facility leased from Standard Properties, Inc. This facility is in Gaithersburg, MD, and contains 42,000 NSF of laboratory and office areas. Personnel moved into the building in stages between March and July 1997.

Blossom Point

In May 1998, ARL conducted a ribbon-cutting and dedication ceremony for the new Acoustic/Electro-Optic Propagation Research Site at the Blossom Point Research Facility, MD. This completes a BRAC initiative by relocating the capability from WSMR. At a cost of $2.5M, the new site boasts two acoustic ranges that will facilitate the ongoing study of atmospheric effects on acoustic and electro-optic propagation. The site will be

used by the Battlefield Environment Division of the Information Science and Technology Directorate (IS&T) to support activities of all three branches of the military.

Simulation and Computational Analysis Laboratory (SCAL)

The SCAL has been resubmitted to the Army Materiel Command (AMC) for the FY02 MCA Program as ARL's top priority. Meanwhile, lab management is exploring nontraditional funding and programming routes, including partnerships with other agencies.

Watertown

On 24 August 1998, the Army formally transferred the Watertown site to the town of Watertown, MA, ending more than 180 years of service to the country. The Watertown Arsenal Development Corporation, acting for the town, paid $7.5M for 30 acres of land, while the town received another 7 acres at no cost. The transfer ceremony was held in the historic Commander's Quarters, which is to be renovated and used for community activities. The 7 acres around the mansion, including the landscape by Olmsted, will be used as a public park.

Woodbridge Research Facility (WRF)

In June, after nearly 50 years of Army control, ownership of WRF was transferred to the U.S. Fish and Wildlife Service, in accordance with BRAC 91 and the FY95 Defense Military Construction Appropriations Act. The Woodbridge property will be joined to the adjacent Marumsco National Wildlife Refuge to form the new Occoquan Bay National Wildlife Refuge.

Regionalization

The ALC Civilian Personnel Advisory Center (CPAC) continues to implement regionalization, which became effective in October 1997 when most operations of the ALC Civilian Personnel Office were centralized in the Northeast Regional Civilian Personnel Operations Center (CPOC). Because of the implementation of the Personnel Demonstration Project in June 1998, ARL requested centralized servicing of personnel for all ARL sites. The Department of Army (DA) approved this request, and in June 1998, the ALC CPAC successfully transitioned the servicing of ARL personnel at WSMR; at National Aeronautics Space Administration (NASA) sites—Glenn Research Center (formerly the Lewis Research Center) in Cleveland, OH, and Langley Research Center in Hampton, VA; and at the Georgia Institute of Technology, Atlanta, to the ALC CPAC. This servicing change added more than 300 employees to the population serviced by the ALC CPAC.

Early in 1998, AMC decided that the Adelphi Procurement Office and the Army Research Office (ARO) should join the AMC Acquisition Center to be headquartered at APG. In October, the two offices were made *provisional* parts of the center, with full integration expected early in 1999.

Partnerships

ARL is pursuing many types of partnerships with academic institutions and private industries to focus state-of-the-art research on Army needs. In addition to the Federated Laboratory (FedLab), ARL operates a number of congressionally mandated technology transfer programs and an extensive educational outreach program. The lab also conducts a broad spectrum of international cooperative research activities.

For example, in February 1998, the Director joined community leaders from Northeastern Maryland to sign a charter establishing the APG Science and Technology Board. The board will provide a forum for bringing together federal, state, and local government with academia and industry to strengthen technology education and growth in the area.

HBCU/MI

ARL has continued the development of education partnership agreements with Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) bringing this year's total agreements to 21: Alcorn State, Bowie State, Clark Atlanta, Florida Agricultural and Mechanical, Grambling State, Hampton, Howard, Jackson State, Lincoln, Morgan State, New Mexico State, and North Carolina Agricultural and Technical State universities; City College of New York; Southern Universities; Southwestern Indian Polytechnic Institute; University of California at Los Angeles (UCLA); University of the District of Columbia; University of Houston; University of New Mexico; University of Texas at El Paso; and the University of the Virgin Islands.

Six HBCU/MI partners participate in FedLab and four participate in the Army High-Performance Computing Research Center (AHPCRC). Currently, ARL employees serve as adjunct professors at three HBCU/MI: Clark Atlanta, New Mexico State, and Tuskegee universities.

ARL has continued the Science and Technology Academic Recognition System (STARS), established during FY96, which is a training and development program designed to reach talented students at HBCU/MI who are enrolled in a science, engineering, or mathematics curriculum. In FY98, ARL recruited an additional four STARS fellows, bringing the total number to seven. The program offers up to $20,000 for tuition and expenses during the senior undergraduate year and up to $30,000 for each of two years of graduate school. This year's recruitment represents a total of $700,000 that ARL has committed to STARS recipients.

Partners in Education

The Partners in Education (PIE) program is a national program in which schools and business, government, or trade associations join together to improve the quality of youth education. Historically, the ARL-APG site has enjoyed strong ties with the John Archer School and Churchville Elementary School, both in Harford County, MD. In fall 1997, ALC implemented an Adopt-a-School program and formed partnerships to focus support to two local Maryland schools—Paint Branch High School, Burtonsville, and Beltsville Academic Center, Beltsville.

During FY98, ARL continued its active Education Outreach program, adding one new institution to total 38 Education Partnership Agreements (see supplement). Three of ARL's sites (APG, ALC, and WSMR) have active programs with local schools and colleges. Under these agreements, lab scientists and engineers support a variety of math and science educational activities and are mentors for students conducting research projects. In addition, over the years, the lab has transferred more than $6M (original cost) in equipment to educational institutions that participate in the program.

Under its open laboratory initiative, ARL pursues other cooperative and collaborative projects, encouraging its researchers as they work in other laboratories; providing researchers from outside the lab access to ARL facilities; and fueling the exchange of researchers, ideas, information, and results to and from other labs. For the year (FY98), the lab reported that 107 of its scientists and engineers had worked outside ARL and that

188 guest researchers had worked at ARL. In addition, 60 postdoctoral researchers had worked at the lab.

Domestic Technology Transfer

Small Business Innovation Research (SBIR)

Through the SBIR program, the Army gains access to the technological advances of small, innovative firms with fewer than 500 employees. The Army sets aside specific funding for high-quality research or research and development proposals of innovative concepts to solve Army/Department of Defense (DoD)-related scientific or engineering problems, especially those concepts that also have high potential for commercial use.

The DoD's SBIR program requests proposals from small businesses by advertising its opportunity topics in two solicitations each year. The Army and ARL participate predominately in the second solicitation, thus allowing for an orderly award of contracts earlier in the fiscal year. ARL is a consistent leader in the Army SBIR program and annually averages about 20 percent of total Army SBIR funding.

The SBIR program consists of two stages or phases. Phase I awards enable recipients to demonstrate the concept feasibility of their proposals. For FY98, ARL awarded 30 new Phase I contracts at about $100,000 each. Successful Phase I recipients are invited to submit Phase II proposals; Phase II contracts enable recipients to establish the proof of principle and to produce a prototype. ARL awarded 14 new Phase II contracts during FY98 at $750,000 each. The ARL's SBIR budget for FY98 was about $14M.

For 1998, ARL and two small businesses working SBIR projects with the lab were selected for two of the five SBIR Quality Awards given. The Army SBIR Program Management Office sponsors an annual Quality Awards Program that recognizes top Phase II projects for their technical achievement, contribution to the Army, and potential for dual-use commercialization. The ARL-sponsored companies that were honored were Analytic Power Corporation of Boston for its work on extremely lightweight fuel cells, and Lynntech, Inc., College Station, TX, for portable power (monopolar fuel cells).

Small Business Technology Transfer (STTR)

The STTR program is a separate program operated within the SBIR program that was created by Congress to foster collaborations between the small business community and research institutions and to involve these communities in federal R&D more effectively. The program is administered by the ARO. ARL provides technical support and evaluates technical proposals submitted by small businesses. ARL currently has no STTR projects.

Independent Research and Development

Independent Research and Development (IR&D) efforts are planned, performed, and funded by companies to maintain or improve their technical competence or to develop new or improved products. Industry's annual IR&D expenditures are estimated to be greater than $2B. As manager of the Army-wide IR&D program, ARL works closely with industry and government representatives to ensure that industry is aware of Army technology needs. Current efforts to communicate these needs include attending technical interchange meetings and AMC's ongoing conferences with industry R&D executives. Through these interactions, ARL articulates its interests and companies see opportunities to tailor their IR&D efforts to address ARL and Army technology needs and to enhance their technical superiority in both domestic and international markets.

International Technology Transfer

In the international area, ARL had especially strong interaction with the United Kingdom (UK), Germany, and Israel. Overall, the lab currently has 19 active and 5 proposed data or information exchange annexes, 10 active and 4 proposed project agreements, and 5 new cooperative projects through the European Research Office (U.S. Army Research, Development, and Standardization Group). In addition, the lab participated in two Technology Working Group meetings (France and Israel) and three bilateral executive oversight meetings (UK, Germany, and Sweden), as well as two executive meetings of The Technical Cooperation Program. Four ARL scientists participated in the ARL personnel exchange (APEX) program, and ARL hosted seven exchange scientists for long-term research assignments.

Personnel

Personnel Demonstration

In the FY95 Defense Authorization Act, Congress empowered the National Performance Review Science and Technology Reinvention Laboratories to design and Experiment with *alternative civilian personnel systems.* The purpose of the resulting personnel demonstration program is to enhance the effectiveness of DoD laboratories by allowing greater managerial control over personnel functions and, at the same time, expand the opportunities available to employees through a more responsive and flexible personnel system. For the Army, the personnel demonstration involves almost 8,000 civilian employees in four science and technology (S&T) organizations, including ARL; the Missile Research, Development, and Engineering Center (MRDEC); the Corps of Engineers Waterways Experiment Station; and the laboratories of the Medical Research and Material Command.

From January 1995 through March 1998, ARL worked on the design, which was published in the *Federal Register* on 4 March 1998. Conversion to the alternative civilian personnel system occurred in June 1998 for all eligible General Schedule employees, and January 1999 will mark the end of the first rating cycle.

In February 1998, seven members of the ARL staff were part of the 37-person Army Personnel Demonstration Team that received Vice President Al Gore's Hammer Award for Excellence. This award is presented to teams of federal employees who have made significant contributions in support of the principles of reinventing government, which are putting customers first, cutting red tape, empowering employees, and getting back to basics.

Diversity

In September 1998, the Director appointed members of a Diversity Board, selecting from some 40 nominees from across the lab. This board will provide advice and recommendations to the Director on diversity-related issues. About the same time, the Director announced that the lab had contracted with MACRO International to help guide the building and leveraging of diversity.

ARL Fellows

ARL encourages its scientists and engineers to seek national and international recognition. In keeping with that goal, an ARL Fellows program was established to recognize the best scientific and engineering talent at the lab. The ARL Fellowship is an honorary

group that serves as a consultative asset to the Director. To become a Fellow, individuals must have demonstrated excellence in technical work over an extended period and exerted positive influences on other members of ARL's technical staff.

In June 1998, ARL produced a pamphlet that gives a brief history of the ARL Fellowship and a brief sketch of each Fellow member. These sketches include each member's significant accomplishments that led up to being named an ARL Fellow.

Greening

The ARL military component has developed a course to provide civilians with a basic understanding of the Army through informal classroom instruction and actual soldier experiences. In May, ARL hosted the AMC *Greening the Workforce* training at APG. The three-day course included an introduction to DoD and DA, the military rank structure, and the role of each branch of service; a ride in a helicopter and a tank; firing the M16A2 rifle and lunching on Meals Ready to Eat (MRE); and briefing on Army Modernization and the Army After Next (AAN).

ARL Reshape

As a result of the FY95 closure of the Watertown, MA, installation and the subsequent transfer of the property, which occurred during the fourth quarter of FY98, the ARL Watertown caretaker staff was terminated effective 30 September 1998. Through the success of outplacement programs, several employees were placed before the termination action. Eight employees were ultimately separated; four through discontinued service retirement and three because of expiration of term appointments.

Awards

Hammer Awards

Army Personnel Demonstration Team
FedLab Implementation Team
Turbine Engine Diagnostic (TED) team
DoD SBIR process reform

DA R&D Achievement Awards

Michael Scanlon
Gary L. Wood and Brian P. Ketchel
Paul Shen

DA Meritorious Civilian Service Award

Charles D. Boylan
Sandra Z. Walter

DA Superior Civilian Service Award

Arthur Gauss Jr.
Bruce R. McCommons
Andrus Niiler
Larry A. Peterson
John D. Powell
Norman D. Smith

Best Paper Awards

Doran Smith—Bronze Medallion, 21st Army Science Conference

Neelam Gupta and Dr. Raschid Dahmani—Honorable Mention, 21st Army Science Conference

Meimei Tidrow—6th Annual AIAA/BMDO Technology Readiness Conference

Other Awards

Louise C. Sengupta—Women in Science and Engineering (WISE) Award for Engineering Achievement

Wayne B. Anderson—Army, Deputy Chief of Staff for Manpower and Personnel Integra tion (MANPRINT) Technology, Research and Development Award

David B. Durbin—Runner-up of the Army, Deputy Chief of Staff for MANPRINT Technology, Research and Development Award

James S. Ainsworth, Otto H. Heuckeroth, Linda G. Pierce, Wayne B. Anderson, Allan Davidson, MAJ James Day, MAJ Terry Johnson, and Jim A. Faughn—Army, Deputy Chief of Staff for MANPRINT, MANPRINT Assessment Team Advanced Warfighting Experiment Special Achievement Award

Richard S. Camden, Patricia H. Jones, Peter J. Grazaitis, Michael G. Golden, Priscilla A. Devonshire, and Kim F. Fluitt—Army Superior Unit Award given to the Joint Laboratory-Advanced Concept Technical Demonstration (JL-ACTD) of Human Research and Engineering Directorate (HRED)

Michael J. Kosinski, Nickey A. Keenan, and Dennis M. Hash—Certificate of Achievement from Commanding General (CG), AMC, for serving as Assistant—M1 Tank Bustle Rack Extension Project

Mary E. Ritondo—Federal Women's Program Supervisor/Manager of the Year Award

Michael W. Starks—1998 Military Operations Research Society Rist Prize

Yolanda L. Hinton—National Technical Association *Outstanding Minority Woman in Science Award*

Wolf Elber—American Society for Materials and Testing Award of Appreciation, 2nd International Symposium on Fatigue Crack Closure

Renee C. Lake and Chester W. Langston—NASA Team Excellence Award for Piezoelectric Aeroelastic Response Tailoring Investigation Project

Mark W. Nixon, William T. Yeager, Paul H. Mirick, Jeffrey D. Singleton, Chester W. Langston—NASA Team Excellence Award for Wing and Rotor Aeroelastic Testing System

Thomas W. Reader—Association of Old Crows 1998 Life Achievement Award

Jack O. Grynovicki—Special 1998 Payne Award from Deputy Under Secretary of the Army

Jim Gantt—Bowie State University Honorary Doctorate

Keith Wilson—Acoustical Society National Award for Young Scientists and Engineers

LTC Robert Hammell—*Who's Who in Science and Engineering 1998–1999 and 2000 Outstanding Scientists of the 20th Century*

Deryn Chu—SBIR Achievement Award

Jih-Fen Lei—R&D 100 Award, awarded by *R&D Magazine*

Average Passage NASA Code Team—NASA's *Turning Goals into Reality* Award

Michael A. Stroscio—Harry Diamond Memorial Award of the IEEE

Thomas G. Kile—Baltimore Federal Executive Board (BFEB) Silver Medal for Outstanding Federal Professional

Vallerie B. Thomas and Jennifer A. Simms—BFEB Bronze Medals for Outstanding Federal Paraprofessional

Financial Review

Resources

Because of the efforts of the DoD to reduce costs, cut staffing levels, and improve business processes, ARL was faced with a number of challenges during FY98. Many of these challenges may have long-term and far-reaching financial management implications. Endeavoring to improve the laboratory's strategic position for responding to the significant changes anticipated over the next few years, ARL initiated studies to view the effects on base support levels and the impact on mission requirements because of projected Quadrennial Defense Review reductions.

ARL continued efforts initiated in FY96 to adjust internal programs in response to decreased funding levels and to expand its external FedLab partnerships. Several directorates projected shortfalls early in FY98, and directorate solvency was closely monitored. Some reallocation of funds was necessary to cover shortfalls at the APG site as a result of a shortage of incoming customer work and unexpected costs associated with the move of the Weapons and Materials Research Directorate to the new Rodman Research Facility. Reducing additional staff was not necessary to remain solvent in FY98 and to meet FY99 financial goals. Throughout the year, the lab adjusted workloads and curbed discretionary spending in both overhead and technical areas. These corrective actions allowed ARL to successfully operate within budget and exceed the DoD's established obligation goals.

Revenue

ARL's total revenue decreased 4.2 percent ($22.2M) from FY97 ($523.6M) to FY98 ($501.4M) despite a 7 percent increase across the board in Army Research, Development, Test, and Evaluation (RDTE) mission funding.

Increases were realized in RDTE funding ($9.6M) and external program funding ($1.8M), while decreases were realized in customer funding ($9.6M), Office of the Secretary of Defense (OSD) funding ($13.7M), total Defense Advanced Research Agency (DARPA) program funding ($2M), internal program funding ($3.8M), and operations and maintenance, Army (OMA) funding ($4.7M). The substantial 63 percent OMA funding reduction was due primarily to the elimination of the Watertown site caretaker requirement and a cut in support for the Standardization Program.

The revenue table excludes BRAC, Major Shared Resource Center (MSRC), and DARPA external funding from total revenue. These funding sources are either a large onetime requirement or primarily external programs and would skew ARL's financial picture if included as part of the budget. The variance between FY98 RDTE planned program and actual program was not significant (0.2 percent).

Revenue	FY97 actual	FY98 projected	FY98 actual	FY98 change	FY99 projected
	$ Millions				
6.1 Basic Research	96.6	96.8	94.8	–2.0	90.5
6.1 Federated Laboratory	17.7	23.9	26.3	2.4	21.7
6.2 Applied Research	122.4	126.2	126.1	–0.1	108.5
6.4 Demonstration/Validation	0.0	0.8	0.7	–0.1	0.0
6.6 Technology Analysis	61.4	61.1	62.9	1.8	64.2
6.6 Management Support	40.9	37.1	38.5	1.4	37.6
6.7 Operational Systems Development	1.8	0.3	1.1	0.8	1.4
RDTE Subtotal	340.8	346.2	350.4	4.2	323.9
Customer Reimbursable	82.8	77.6	73.2	–4.4	78.2
DARPA (internal)	6.1	6.5	2.3	–4.2	1.2
OSD	86.4	67.2	72.7	5.5	71.0
Other (OMA, PAA)	7.5	5.2	2.8	–2.4	0.7
Total Revenue	523.6	502.7	501.4	–1.3	475.0
DARPA External	52.6	63.6	54.4	–9.2	55.8
MSRC/HPC	42.0	54.1	60.6	6.5	51.0
BRAC	10.4	0.0	0.0	0.0	0.0

Note: This profile includes ARO data in each fiscal year.

ARL's mission program took two general reductions in FY98. The first reduction was the distribution of nonspecific congressional adjustments that DA distributes across all projects. A total of $12.8M was taken from ARL's program to reduce work performed by Federally Funded Research and Development Centers (FFRDCs) and consulting contractors, to adjust programs for revised inflation rate projections, and to provide funding for SBIR and STTR programs. The second general reduction, a congressionally directed rescission of $1.3M, was taken in February because of further inflation adjustments.

The financial impact of FY98 congressional actions on specific ARL programs is shown below.

ARL Program	$M
Defense Research Sciences	–3.0
University and Industry Research Centers	–1.2
Institute for Advance Technology	+1.0
Hardened Materials	+3.0
Sniper Projectile Detecting and Cueing (PDCue)	+2.5
Passive Millimeter Wave Camera	+5.0
Electric Gun	+4.0
Liquid Propellant	+4.0
Medical Teams	+3.0
Center for Geo Sciences	+7.5
Focal Plane Array CM	+1.0
Autonomous Vehicle	+0.2

AMC and DA continued bill payer procedures initiated in FY96, targeting FY98 programs with low priority or low obligation and disbursement rates as sources for covering critical unfunded requirements. The Electromagnetic portion of the Electric Gun program was identified as a bill payer because of its low DA priority. This resulted in a program funding reduction of $2.4M.

An important aspect of ARL's transformation into a FedLab is the increased focus on core business areas. Focusing ARL's resources on key technology areas rather than spreading them thinly over a broad technology base allows ARL to concentrate on new and emerging technologies that meet the needs of Force XXI, Army/Joint Vision 2010, and AAN. The following provides a breakout of FY98 revenue by business area ($M).

Business Area	$M
Human Engineering	26.6
Information Systems Technology	52.8
Sensors and Electronic Devices	77.8
Survivability/Lethality Analysis	46.1
Weapons and Materials Research	100.7
Vehicle Technology Center	9.5
Corporate Information and Computing (High-Performance Computing and direct General and Administrative (G&A))	68.4

Operating Expenses

Total operating expenses dropped $22.2M or 4.2 percent in FY98. All categories had reductions in response to the decreased revenue. Substantial reductions occurred in labor, $5.2M; other internals, $7.5M; indirect overhead, $1.6M; and general and administrative, $5.2M. Contracts and actions with other government agencies also continued to decrease in FY98 by $2.7M. In FY98, the actual cost to support a direct work hour was $78.36 per hour, $1.68 less than what was projected last year. The projected FY99 cost to support a

direct work hour is anticipated to be $79.59 per hour. No large non-BRAC infrastructure improvements occurred in FY98.

The ARL Director continued the Director's Research Initiative Program in FY98. This program encourages innovative research within ARL that exhibits high potential for payoff. Proposals are competitively awarded using laboratory mission funding. In FY98, proposals totaling $3.5M were awarded.

Laboratory Overhead

ARL overhead is funded through a combination of appropriated overhead funds and a distribution of costs to each technical mission and customer-funded labor hour. If the appropriated funding remains constant, every dollar saved through efficiencies will reduce the cost distributed to the benefiting technical mission and customer-funded programs. Because of revenue constraints, management continues to aggressively identify areas that could be deferred or reduced.

General and Administrative

Overhead ($ Millions)

						Projected
	FY 94	**FY 95**	**FY 96**	**FY 97**	**FY98**	**FY 99**
Distributed	41.9	40.2	32.3	41.1	35.2	31.3
Appropriated	52.5	47.6	50.0	39.6	40.3	39.6
Total	94.4	87.8	82.3	80.7	75.5	70.9

G&A overhead expenses are costs that are less than 100 percent attributable to a specific mission, but benefit all ARL's technical and customer programs. The G&A budget is funded through a combination of appropriated funding and cost distribution to technical and customer-funded programs. Included are corporate management, base operations, and general installation maintenance functions. In FY98, the actual G&A expenditures were $75.5M, or $2.5M below the original approved budget. The reductions are attributable to general austerity measures and selected cuts in operational costs for the Chief of Staff organization and service elements of the Corporate Information and Computing Directorate. The savings reflect management's emphasis on minimizing the financial burden to our technical program and getting the maximum output for our R&D dollars. The projected $4.6M reduction of G&A costs in FY99 reflects a transfer of $1.7M to indirect costs as a result of a realignment of the budget function and a $2.9M-reduction in costs. As shown in the G&A trend chart, ARL has made significant progress in terms of real growth. Savings are projected to continue in future years, despite growth in fixed costs because of new construction adding approximately 482,000 NSF of office and lab space between FY96 and FY01.

Indirect

Overhead ($ Millions)

					Projected
FY 94	**FY 95**	**FY 96**	**FY 97**	**FY98**	**FY 99**
38.1	33.1	34.6	31.4	29.8	34.0

Indirect overhead expenses are costs that are 100 percent attributable to the mission but do not produce the primary research effort. These expenses, include supervision above the first-line supervisor and administrative support at the directorate/center level. These expenses are distributed to the technical mission and customer-funded programs. Indirect costs dropped $1.6M in FY98 because of efficiencies made within our technical directorates. The projected increase in FY99 includes the transfer of $1.7M because of a realignment of the budget function, $1.2M in costs from the host installation at APG, and $2.3M of onetime relocation-related costs, offset by $1.0M in cost reductions.

Financial Management Initiatives and Significant Accomplishments

ARL continued to upgrade automation in program and budget areas. Emphasis was placed on enhancing dissemination of information and guidance by establishing an ARL intranet-linked web site. This site provides easy access to management and technical directorates for up-to-date information on program and budget planning, formulation, and execution. As of the end of FY98, the following information was available on line: current funding guidance, S&T planning information, ARL congressional descriptive summaries, Director's Research Initiative Program, the Training and Doctrine Command (TRADOC) S&T Review, and science and technology objectives (STO) guidance. Work is expected to be completed in early FY99 on the interactive web site for maintaining the Technology Planning Database (TPD), the primary source for out-year programming information. This will allow for easier inputting of data, decreased server usage, and reduced directorate workload.

FY98 Budget Execution Highlights

ARL received 69 percent—$241.8M—of the anticipated FY98 RDTE mission program at the beginning of the fiscal year. DA held 25 percent—$87.6M—of the program to adjust for general congressional reductions, and OSD held 6 percent—$21.3M—for potential congressional changes to specific programs (congressional worst case scenario), for centrally managed programs, and for unresolved DA and AMC issues. The Revised Approved Program (RAP) was released in January. With it, $74.8M was released. This was the balance of the 25 percent held minus $12.8M that was held for general congressional reductions. DA continued to hold 6 percent—$21.3M—for congressional changes to specific programs. Of this money, $1.5M that was on hold for the chemical-biological program was withdrawn from the ARL direct program and consolidated at OSD, and $1.2M was rescinded in February based on revised inflation assumptions. The remaining program on hold was released in February and March, $5.0M; May, $3.8M; and July, $11.0M. The late release of funding for C-GAR, IAT, and PDCue resulted in late contract awards on these programs. Despite this, ARL's mission program exceeded the DA obligation goals throughout the year. At year end, ARL's FY98 RDTE program was 98.6 percent obligated against a goal of 95 percent. The FY98 OMA program was 100 percent obligated.

Continuous Improvement

ARL addresses the Army's needs across the continuum—today's Army of Excellence, Force XXI, Army/Joint Vision 2010, and AAN. With its Performance Evaluation Construct and business planning processes, the lab ensures that its technical program is of high quality, relevant to the warfighter, and responsive to its customers. The Technical Assessment Board (TAB) evaluates the quality of the ARL research program. The Stakeholders' Advisory Board (SAB) ensures that the program is responsive to the vision of the Army's senior leadership. In addition, the ARL Board of Directors, composed primarily of the technical directors of the AMC RDECs, continues its annual review of ARL's work to ensure ARL supports its principal Army customers.

Performance Evaluation

As part of the recently completed Pilot Project for Performance Measurement under the Government Performance and Results Act (GPRA), ARL took up the challenge of solving a problem that has faced the R&D community for decades: How can one objectively and quantitatively evaluate progress in an R&D program or organization toward proposed outcomes? ARL developed a system to evaluate its performance against a set of objective standards or goals that are related to outcomes specified in the ARL mission statement and strategic plan. This Performance Evaluation Construct is a semiquantitative process that builds on the three pillars of peer review, customer feedback, and metrics to answer three basic questions about the lab's programs: Is the work relevant? Is it of high quality? Is the organization productive?

As the only R&D organization designated as a GPRA pilot project, ARL has been selected to mentor other agencies and activities throughout the government in the techniques it has developed. At the request of the Director of Defense Research and Engineering (DDR&E) and the Assistant Secretary of the Army for Research, Development, and Acquisition (ASARDA), the lab has put much effort into introducing the Construct throughout the DoD labs, holding seminars and training sessions, and giving invited talks. Outside DoD, ARL has been a leading participant in the Government Research Roundtable, which has been developing approaches to the various challenges of GPRA for the entire federal technical community.

Peer Review

Three years ago, ARL contracted with the National Research Council (NRC) of the National Academies of Science and Engineering to institute the ARL TAB to provide peer review of its technical programs. By using the NRC to establish and administer the TAB, ARL is assured of obtaining a review that is completely independent and of the highest possible repute. This candid feedback and the constructive criticism are inherent parts of the peer review process.

The board, with its six panels aligned by ARL business areas, completed its second year's review in July 1997, and the results were published in the TAB's second public report, *1997 Assessment of the Army Research Laboratory* (National Academy Press, 1998). Overall, the report praised many areas of ARL's technical program, calling out some areas as leading the state of the art while identifying others as needing improvement. After a series of meetings between the board and ARL's senior leadership to discuss and clarify these issues, ARL's Director designed an action plan to respond to the points raised by the board.

The TAB continues to function in the manner that ARL had hoped, providing insightful commentary and advice on its technical programs. TAB's third review cycle began in spring 1998 with another round of panel visits to the lab that focused on different segments of ARL's overall program as well as the programs of several of its private sector partners. This is in concert with the principle that FedLab and other related partnering programs are not separate from the in-house program, but rather are integral parts of it. The visit portion of this third cycle is complete, and the TAB has begun the editing process. The third annual report will be published in January 1999. The contract with the NRC for the TAB is expected to be renewed for another three-year cycle.

Customer Feedback

Based on its work under GPRA and research done at the Sloan School of Management at the Massachusetts Institute of Technology (MIT), ARL has identified and segmented its customers and stakeholders and has developed processes to gather feedback of satisfaction from each.

One segment includes those organizations to which ARL provides a specific product, be it a report, an analysis, or a prototype. This group consists of its direct customers, primarily the AMC RDECs, and its reimbursable customers. Since ARL provides a specific deliverable, and that deliverable is based on a documented agreement such as a Technology Planning Annex (TPA) or some other scope of work, the lab has been using a rigorous survey process to capture feedback. Continuing the process that first began in FY94, ARL annually queries its customers, which represent approximately 400 different specific tasks it performs, asking for responses on the quality, utility, and timeliness of the product delivered and on the helpfulness of the ARL professional staff members. Customers rank the lab on a 1 to 5 (5 excellent) scale.

The most recent survey of the TPA customers was completed in June 1998. It had an overall response rate of 52 percent. As can be seen in the accompanying chart, ARL's scores had risen steadily until last year when its scores dropped because of the dislocations related to BRAC actions. Discounting these BRAC-related moves returns ARL's scores to about the same high level as in FY96. In FY98, the upward trend continued.

The survey sent to ARL's customers is altered slightly and used to query its paying customers, as identified on reimbursable customer orders. The last reimbursable customer survey was done in spring 1997 on products delivered in FY96. Based on a response rate of nearly 40 percent of the 260 surveys sent, ARL improved slightly from the previous year, as can be seen in the accompanying chart. The overall performance score rose from 4.31 to 4.34.

ARL has also identified other stakeholders who have a major interest in the quality and reliability of its work: the soldiers in the field and the Army's senior leadership. Generally, these groups only see ARL's work after it is embedded in a final product, such as a tank or a helicopter. To obtain feedback from these groups and to increase the feeling of *ownership* by the Army's senior leadership, ARL established the SAB. The AMC Commander chairs the SAB, whose members include nine senior Army staff members at the three-star (or civilian equivalent) level and the Deputy Commander of the U.S. Army TRADOC. This body gives ARL strategic guidance to ensure that its work is tightly coupled to the Army's needs and that it is being responsive to the leadership.

The SAB held its third meeting at Adelphi in July 1998. General Johnnie E. Wilson, AMC Commander, chaired the session, which was attended by the members of the

Army's senior leadership or their principal representatives. Briefings and demonstrations were presented and discussions were held concerning how ARL is meeting the challenges of increasing and changing workload and decreasing budgets and staff. Particularly, the members discussed ARL's intentions to continue its various reinvention initiatives in the areas of expanding the FedLab concept and concentrating its efforts on core business functions. All the SAB members had high praise for ARL, its work and its people, and they all pledged their support as the lab goes through these difficult times. This year's meeting ended on a particularly high and special note as the SAB adjourned to the auditorium where they joined a standing-room-only crowd to witness the presentation of two of the Vice President's Hammer Awards for reinvention efforts. The Assistant Secretary of the Army and the Deputy Director of the National Partnership presented the awards for Reinventing Government.

Metrics

People frequently look for quantifiable metrics as indicators of performance, but such an approach has consistently proven unworkable and inappropriate in R&D. Counting achievements like patents and papers measures activity, but does not necessarily reflect the quality or utility of the work done. Even so, metrics do indicate the functional or operational health of the organization, so ARL collects data on over 50 metrics for two basic purposes (see the supplement to this review for specifics).

The first purpose is simply to track information that the lab is required to report to higher headquarters or that might be useful to know, such as financial and personnel data, as well as activity indicators, including the number of patents and papers. As long as these numbers are within some accepted bounds, either defined by regulation or by common sense, they are tracked by the functional office chiefs and only reported to the Director on an exception basis.

Second, the metrics data provide a tool for the Director to use to improve the research environment of the laboratory. For example, the Director believes that the number of guest researchers working on-site at ARL should be at a certain level. Likewise, he believes that the educational level of the work force should be high. Therefore, the Director has chosen to closely observe a subset of about 15 of the roughly 50 metrics that ARL tracks. He implements such goals by placing them in the performance standards of his senior management team, thus coupling ARL's metrics system to individual performance and giving those leaders the incentive to move the parameters in line with his expectations. This was favorably noted in a recent General Accounting Office (GAO) report[1] on this topic.

In FY98, the number of metrics to which the Director devotes special emphasis was increased from 15 to 17, reflecting changes in emphasis as well as goals met. Of those 17, ARL met or exceeded the goal for 6 and came close in the others, indicating that productivity as reflected by these output measures increased in spite of work force downsizing, internal reorganizations, and site consolidations. The 6 metrics for which ARL met or exceeded the goals are—

- percent of top tasks met,
- STOs (percent of STO milestones accomplished),

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[1]*Performance Management: Aligning Employee Performance With Agency Goals at Six Results Act Pilots*, U.S. General Accounting Office, GAO/GGD-98-162 (September 1998).

- number of refereed papers and proceedings,
- ratings from TPA customers (via surveys),
- number of employees on academic training, and
- total semester credit hours of academic training completed.

While the lab underperformed in internal technical reports, it is important to recognize that the actual performance of refereed papers and proceedings continues to grow dramatically compared to the FY96 and FY97 performance. This growth indicates both a trend toward greater per capita productivity (which has been seen in several metrics) and the changing nature of ARL as it continues to move away from the developmental engineering orientation of its predecessors and toward the world-class research laboratory that it is becoming.

In the technology transfer category, the number of guest researchers into and out of ARL continues to slide. This is a disturbing trend and is, at least in part, connected to the general downward pressure on budget and force structure.

In spite of ARL downsizing the work force during the last few years and severely limiting hiring, the percentage of S&Es with Ph.D.s has remained just under 27 percent. Although, the number of employees on long-term training has more than doubled since FY94, this flattening of the curve is one of ARL's main concerns in achieving the long-term goal of having at least 40 percent of the S&Es holding Ph.D.s.

While the funding from reimbursable customer orders was just slightly below the revised FY98 goal, the performance on this metric has to be put in perspective by recognizing that ARL's reimbursable customers are facing the same funding constraints that the lab is facing. ARL is expanding its marketing efforts to target new potential, customers while keeping the past customers satisfied. Significant progress can be seen in the indirect overhead, which has decreased during the past few years because of decreasing support functions and reinventing or eliminating processes.

As an indication of the overall success of this metrics pillar of our Construct, since 1993—the number of guest researchers into ARL is up 36 percent, the number of NRC postdoctoral Fellows is up 88 percent, the percentage of S&Es with a Ph.D. degree is up 20 percent, the number of refereed journal articles is up 257 percent, and the number of employees on long-term training is up 88 percent.

While these numbers do not directly indicate the success of ARL's research program, they do indicate a substantial improvement in the laboratory environment in which world-class research can take place.

Technical Objectives — Status

Human Research and Engineering

T-H.1	Task and Workload Modeling for Cognitive Engineering (SG-H.2)	Green
T-H.2	Effect of Varying Physical Load Parameters and Auditory Display Technologies on Message Intelligibility for the Dismounted Soldier (SG-H.1)	Green
T-H.3	Enhanced Performance Degradation Modeling in IMPRINT (SG-H.4, SG-H.5)	Green
T-H.4	Soldier Performance on Slippery Surfaces (SG-H.3)	Green
T-H.5	Human Factors in Organizational Maintenance Diagnostics Processes (SG-H.4, SG-H.5)	Yellow

Information Science and Technology

T-I.1	Advanced Battlefield Visualization Infrastructure (SG-I.1, SG-I.5, SG-I.6)	Green
T-I.2	Wargaming and Simulation of Real-Time Battlefield Data and Information (SG-I.1, SG-I.3)	Green
T-I.3	Defensive Information Warfare (SG-I.4)	Green
T-I.4	Wireless Multi-Hop Soldier LAN (SG-I.2, SG-I.4)	Green
T-I.5	Battlefield Forecast Model Verification and Validation (SG-I.1)	NA
T-I.6	Prototype Atmospheric Profiler (SG-I.1)	Green
T-I.7	Tactical Operations Center Intelligent System (SG-I.1, SG-I.6)	Green
T-I.8	Collaborative Platform Intelligent System (SG-I.1, SG-I.6)	Green

Sensors and Electron Devices

T-S.1	Adaptive Target Detection (SG-S.7)	Green
T-S.2	Multidomain Smart Sensor Demonstration (MDSS) (SG-S.1)	Green
T-S.3	Dual Band Quantum Well Infrared Photodetector (QWIP) (SG-S.1)	Green
T-S.4	Modular Neural Network Automatic Target Recognition (ATR) Algorithm (SG-S.3)	Green
T-S.5	Design and Demonstration of Next-Generation HPM Source System (SG-S.4)	Red

Survivability/Lethality Analysis

T-L.1	Air Defense Systems: Theater High Altitude Air Defense (THAAD) SSv and E3 Assessments (SG-L.2)	Green
T-L.2	Aviation Systems: Comanche Chemical Weapon Threat Levels (SG-L.2)	Yellow
T-L.3	C4I/IEW: IW Survivability Analysis of Information Security Systems (SG-L.1, SG-L.2)	Green
T-L.4	Ground Systems: Complete Experimentation and Analytical Design Support of the Crusader Preliminary Design Phase Leading to the PEO IPR in FY98	Green
T-L.5	Munitions: Army Tactical Missile System (ATACMS) Block 1A Follow-On Test Effectiveness Analysis (SG-1.2)	Green

Weapons and Materials Research

T-W.1	Electric Armaments for Direct Fire (SG-A.1)	Green
T-W.2	Rocket Accuracy Technology (SG-A.1)	Yellow
T-W.3	Smart Weapons/Autonomous Platform Technology (SG-A.1)	Green
T-W.4	Future Direct Support Weapons System Support (SG-A.1)	Yellow
T-W.5	Direct Fire Lethality (SG-A.1)	Green
T-W.6	Micromechanics and Failure Modeling (SG-A.2)	Green
T-W.7	Ferroelectric Phase Shifter Materials (SG-A.2)	Yellow
T-W.8	Armor Technology (SG-A.2)	Green
T-W.9	Ultra-Light Ballistically Resistant Materials (SG-A.2)	Green
T-W.10	Counter KE Active Protection Technology (SG-A.2)	Yellow
T-W.11	Damage Tolerant Composite Armor (SG-A.2)	Green
T-W.12	Durability Enhancement (SG-A.2)	Green

Vehicle Technology Center

T-V.1	Army-After-Next (AAN) Fuel-Efficiency Thrust (SG-V.1, SG-V.2, SG-V.3)	Green
T-V.2	Innovative Composite Fuselage Design for Improved Crashworthiness (SG-V.2)	Green
T-V.3	Durability and Damage Tolerance of Rotorcraft Structural Components (SG-V.1, SG-V.3)	Green
T-V.4	Compression System Stability Enhancement (SG-V.1, SG-V.2)	Green
T-V.5	Compressor Tip Clearance and Flow Management (SG-V.1, SG-V.2)	Green
T-V.6	High Temperature MEMS Actuators for Boundary Layer Control (SG-V.1, SG-V.2)	Green
T-V.7	High Temperature Magnetic Bearings (SG-V.1, SG-V.2)	Green
T-V.8	Oil Coking in Hot Section Bearings of AGT-1500 Turbine Engine (SG-V.1)	Green

Organizational Information

Organizations	*Directors*	*Program $M*	*Workforce*	*S&Es*
Army Research Office	Dr. Jim C. I. Chang Phone: 919-549-4203 Fax: 919-549-4348 email: arodir@aro-emh1.army.mil	160.1	97	42
Corporate Information and Computing Directorate	Dr. N. Radhakrishnan Phone: 410-278-6639 Fax: 410-278-5075 e-mail: amsrl-ci@arl.mil	68.4	119	33
Human Research and Engineering Directorate	Dr. Robin Keesee Phone: 410-278-5800 Fax: 410-278-0505 e-mail: rkeesee@arl.mil	26.6	187	125
Information Science and Technology Directorate	Dr. James Gantt Phone: 301-394-2100 Fax: 301-394-5420 e-mail: jgantt@arl.mil	52.8	185	142
Sensors and Electron Devices Directorate	Dr. John Pellegrino Phone: 301-394-2002 Fax: 301-394-5410 e-mail: pell@arl.mil	77.8	337	262
Survivability/ Lethality Analysis Directorate	Dr. James Wade Phone: 505- 678-1196 Fax: 505-678-1198 e-mail: jwade@arl.mil	46.1	290	226
Vehicle Technology Directorate	Dr. Wolf Elber Phone: 757-864-3956 Fax: 757-864-7796 e-mail: w.elber@larc.nasa.gov	9.5	100	69
Weapons and Materials Research Directorate	Dr. Ingo May Phone: 410-306-0646 Fax: 410-306-1043 e-mail: amsrl-wm@arl.mil	100.7	418	310

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